TOOL MAKING

PART II

AMERICAN SCHOOL of CORRESPONDENCE
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TOOL-MAKING

PART II

INSTRUCTION PAPER

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AMERICAN SCHOOL OF CORRESPONDENCE

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TOOL-MAKING

PART II

THREAD-CUTTING DIES

The size of a die is always denoted by the diameter of screw it will cut; a die that will cut a $\frac{1}{2}$-inch screw is called a $\frac{1}{2}$-inch die, irrespective of the outside diameter of the die itself.

Thread-cutting dies are made solid or adjustable. Solid dies are used when extreme accuracy is not required. They are comparatively inexpensive, and may be used to advantage as a roughing die when an adjustable die is used for finishing. Owing to the tendency of dies to change their sizes when hardened, and to the fact that there is no provision for wear, they cannot be used where work must

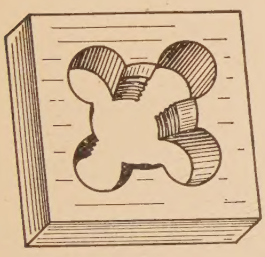

Fig. 111. Square Die.

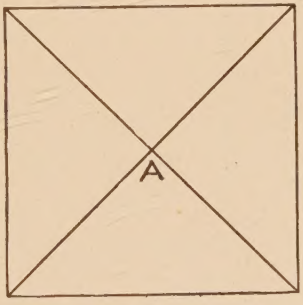

Fig. 112. Locating Center of Die Blank.

be made to gauge. They are extensively used in cutting threads on bolts, and for this class of work are made square, as shown in Fig. 111.

In making a square die, the blank may be machined to thickness and to size on the square edges. One of the flat surfaces should be coated with blue vitriol, or the blank may be heated until it shows a distinct brown or blue color. The center may be found by scribing lines across corners, as shown in Fig. 112. It should be prick-punched at A, where the lines intersect. The die blank may be

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clamped to the face-plate of a lathe, and made to run true by means of the center indicator. If there is no tap of the proper size, and only one die is to be made, the thread may be cut with an inside threading tool, provided the hole is of sufficient size; if not, a tap must be made. If the thread is cut with a threading tool, the size must be determined by means of a male gauge, which may be a screw of the proper size. After threading, the hole should be chamfered to a depth of three to four threads, the amount depending on the pitch of the thread, a fine pitch not requiring as many threads chamfered as a coarse pitch. The chamfering should not be much larger on the face of the die than the diameter of the screw to be cut. Figs. 113 and 114 show two views of a die chamfered and relieved on the cutting edges. The chamfering may be done with a countersink or taper reamer of the proper angle. In the absence of such a cutter, a tool held in the tool-post of the lathe may be used.

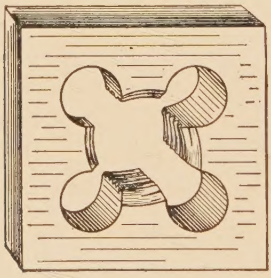

Fig. 113. Chamfering of Die.

Fig. 114. Chamfered Threads.

Most manufacturers making dies for the market give four cutting edges to all sizes up to and including four inches. When dies are made in the shop where they are to be used, custom varies. Some tool-makers advocate three cutting edges for all dies smaller than $\frac{1}{4}$ inch, and five or more cutting edges for dies above two inches. The objection to more cutting edges than are absolutely needed on large dies, is the increase in the cost of making.

When making dies for threading tubing, or for work where part of the circumference is cut away, it is better to give them a greater number of cutting edges than would otherwise be the case.

Rake of Cutting Edges. For general shop work, where the dies are to be used for all kinds of stock, it is advisable to make the cutting

edges radial, as shown in Fig. 115, the cutting edges *A A A A* all pointing to the center. For cutting brass castings, the cutting edges should have a slight negative rake, as shown in Fig. 116, the cutting edges *A A A A* all pointing back of the center.

Clearance Holes. After threading and countersinking (chamfering), screw in a piece of steel threaded to fit the die, and face it off

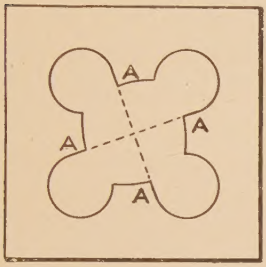

Fig. 115. Radial Cutting Edges.

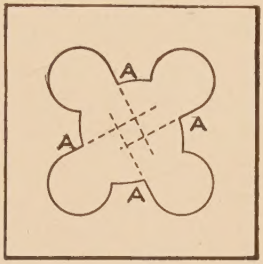

Fig. 116. Negative Rake.

flush. Lay out the centers of the clearance holes on the back of the die, and drill a hole the size of the pilot of a counterbore whose body will cut the right size for the clearance hole. The centers of these holes, for dies having four cutting edges, and from $\frac{3}{8}$ to $\frac{3}{4}$ inch, may be the intersections of a circle having a diameter equal to the diameter of the screw to be cut, and lines drawn across the corners as shown in Fig. 117. Prick-punch these points. For a die having four clearance holes whose centers are laid out as shown in Fig. 117, it is customary to make the clearance holes one-half the size of the die; that is, the size of clearance holes in a $\frac{1}{2}$-inch die would be $\frac{1}{4}$ inch. The width *A*, Fig. 118, of the top of the lands should be about $\frac{1}{16}$ of the circumference of the screw to be cut. The diameter of clearance holes given does not apply to dies smaller or larger than sizes given ($\frac{3}{8}$ to $\frac{3}{4}$ inch), especially if the dies are to be used in the screw machine, as the clearance hole not only provides a cutting edge, but also makes a convenient place for the chips; if these are so small

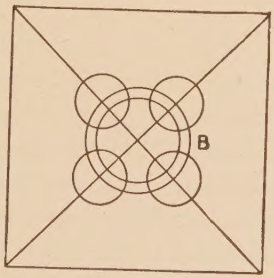

Fig. 117. Layout of Blank.

that the oil cannot wash the chips out, the chips clog the holes and tear the thread.

For small dies, the clearance holes are of a size that allows the chips to collect in the holes without tearing the threads, and are located a greater distance from the center of the die, in order to give sufficient strength to the lands. The desired shape and thickness may be given the sides of the lands by filing. When it is considered advisable to give screw dies above $\frac{3}{4}$ inch larger clearance holes than the size mentioned, they may be located at a distance from the center of the die that will give the desired thickness to the land.

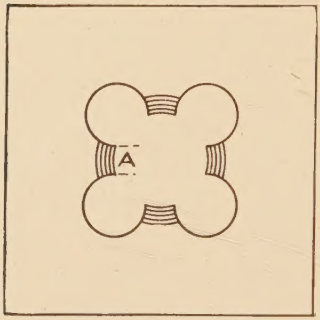

Fig. 118. Clearance Holes.

For screw-machine and turret-lathe work, dies are generally made circular; and as holders for dies are part of the equipment of every shop having screw machines, the dies should be made to fit these holders; but it is not considered good practice to make the diameter of dies less than $2\frac{1}{2}$ times the diameter of the screw to be cut, and the thickness of the die may be $1\frac{1}{4}$ times the diameter of the screw.

ADJUSTABLE DIES

While round dies for screw-machine work may be made solid for roughing out a thread that is to be finished by another die, the finish die should be made adjustable in order that the desired size may be obtained. When making adjustable dies, the same general instructions may be followed that are given for making solid dies, except that some provision must be made for adjustment. This is done by splitting the dies at one side as shown at *A* in Fig. 119. In order that the die may not spring out of shape in hardening, it is advisable to cut the slot from the center of the die, leaving a thin margin as shown at *A*, Fig. 120; after the die is hardened, this may be cut away with a beveled emery wheel. If the thickness at *B* is too great to allow the die to close readily when adjusted to size, the hole shown may be drilled and connected with the clearance hole by means of a saw cut.

If many round dies of the same diameter are to be made, it is economical to have a holder with a shank which fits the hole in the spindle of the lathe; the opposite end should be made to receive the die blanks, which should be turned to fit the die-holder in the screw machine. Fig. 121 shows the holder to be used in the lathe. *A*

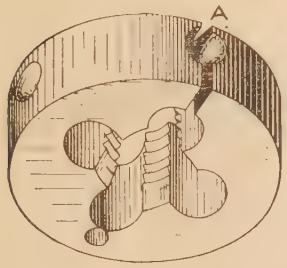

Fig. 119. Adjustable Die.

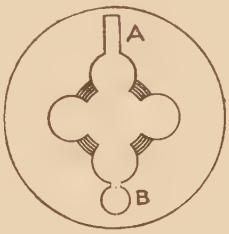

Fig. 120. Margin Left for Hardening.

represents a die blank in the holder; *B* is the shank which fits in the spindle of the lathe; *C* is a recess in the holder to provide for the projection left on the blank when it is cut from the bar, and also provide an opening to receive the drill and tap after they run through the die. After the blank is placed in the holder and secured in position by the

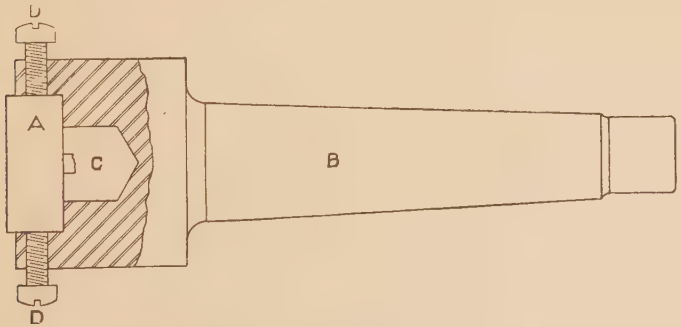

Fig. 121. Die Holder for Lathe.

screw *D D*, the outer surface may be faced smooth and true with the circumference, after which it may be reversed and the opposite side finished to the proper thickness. The die may now be drilled and tapped. Before drilling, the die should be carefully centered in the lathe to insure a full thread in the die; a drill a few thousandths of an inch smaller than tap size should be used in drilling, after which a

reamer of the proper size may be run through. When tapping the thread, it is advisable to use two or three taps of different sizes; the finish tap should be the size of the desired hole in the die, and should be of the form known as *screw-die hob*. Where several taps are used in tapping a die, there should be some difference in the diameter so that any inequality in the shape or pitch of the thread may be removed by the larger tap; otherwise imperfect threads will result. For instance, if three taps are to be used for a $\frac{1}{4}$-inch die, the first tap may be .230 inch diameter; the second .240 inch diameter, and the finish tap .250 inch diameter, if the die is to be solid. If it is to be an adjustable die, the finish tap should be .253 inch diameter, in order to furnish clearance to the lands when it is closed to .250 inch.

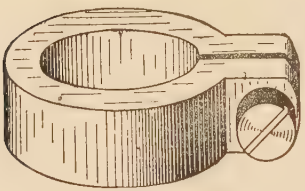

Fig. 122. Clamp Collar.

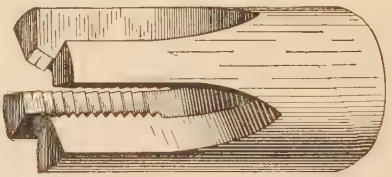

Fig. 123. Spring Die.

Dies should be heated very slowly for hardening, either in a muffle furnace, or in some receptacle to protect them from the action of the fire. When the die is heated to a uniform, low red, it may be immersed in a bath of lukewarm brine and worked back and forth to insure hardening the threads. The temper should be drawn to a full straw color. If it is an adjustable die, the portion marked *B*, Fig. 120, should be drawn to a blue color in order that it may spring without breaking. This may be done by placing this portion of the die on a red-hot iron plate; or the jaws of a heavy pair of tongs may be heated red-hot, and the die may be grasped in the tongs and held until the desired color appears. Do not allow the blue color to extend to the threads, or they will be too soft. When the desired color has been obtained, the die may be dropped into oil to prevent drawing the temper more than is desired.

Spring Screw-Threading Dies. This form of die is adjusted by means of the clamp collar shown in Fig. 122; the die is shown in Fig. 123. In some shops it is the only form of screw-threading die used

for screw-machine work. When so used, it should be fitted to one of the holders on hand, provided there be one of the proper size.

Average proportions of spring dies are given in the Table VII. These sizes are used by a manufacturing concern using a great many screw-threading dies of this description. It is not necessary to follow the proportions given, as they are intended only as a guide, and may be changed to suit circumstances. All dimensions are in inches.

TABLE VII

Spring Screw-Threading Dies

Size of Screw	Outside Diameter	Length
$\frac{1}{8}$ to $\frac{1}{4}$ in.	$\frac{1}{2}$ in.	$1\frac{1}{4}$ in.
$\frac{1}{4}$ to $\frac{3}{8}$ "	$\frac{3}{4}$ "	$1\frac{3}{4}$ "
$\frac{3}{8}$ to $\frac{1}{2}$ "	1 "	2 "
$\frac{1}{2}$ to $\frac{3}{4}$ "	$1\frac{1}{4}$ "	$2\frac{1}{4}$ "
$\frac{3}{4}$ to 1 "	$1\frac{5}{8}$ "	$2\frac{1}{2}$ "
1 to $1\frac{1}{4}$ "	2 "	3 "
$1\frac{1}{4}$ to $1\frac{1}{2}$ "	$2\frac{1}{2}$ "	$3\frac{1}{2}$ "
$1\frac{1}{2}$ to 2 "	$3\frac{1}{4}$ "	4 "

For uniform and well-finished threads, two dies should be used, one for roughing, and one for finishing.

Where many dies of a size are made, it is best to have a holder with a shank fitting the center hole of some lathe. The stock can be machined to size and cut to length. The clearance hole in the back of the die should be first drilled somewhat larger than the diameter of the screw to be cut. For dies up to and including $\frac{1}{8}$ inch, the clearance holes should be $\frac{1}{32}$ inch large; for dies $\frac{1}{8}$ to $\frac{1}{4}$ inch, it should be $\frac{3}{64}$ inch large; for dies $\frac{1}{2}$ inch and over, it should be from $\frac{1}{16}$ to $\frac{1}{8}$ inch large. After drilling the clearance hole, the die should be reversed in the holder, and drilled and tapped the same as a round die, using a hob to finish the threads to size. For general work, the die should have four cutting edges, making the lands about one-sixteenth the circumference of the screw to be cut. Chamfer about three threads. The length of the threaded portion of the die should not exceed one and one-quarter times the diameter of the screw

to be cut. To produce the cutting edges, use a 45-degree double-angle milling cutter, shown in Fig. 124; this cutter should be of sufficiently large diameter to produce a cut as shown in Fig. 125.

The chamfered edges should be relieved, and the cutting edges finished with a fine file. Stamp the size and number of threads on the back end of the die, as shown in Fig. 125, and then harden. The die should be heated in a tube and hardened in a jet of water coming up from the bottom of a tank, in order that the water may enter the threaded portion. The die should be hardened a little farther up than the length of the thread, and should be moved up and down in the bath to prevent a water line; the temper should be drawn to a full straw color.

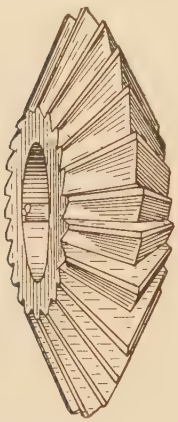

Fig. 124. Double Angle Milling Cutter.

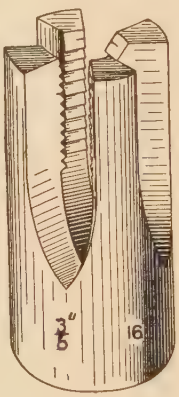

Fig. 125. Die Stamped.

Where many clamp collars are used, castings of malleable iron or gun metal may be made from a pattern; the hole should be cored to within $\frac{1}{16}$ inch of finish size, drilled, and reamed. When the screw-hole has been drilled and tapped and the collar split, it is ready to use. If the surfaces are finished, it adds very materially to the cost.

Die-Holders. When cutting threads in screw machines and turret lathes, dies are held in die-holders, which are constructed in two parts, as shown in Fig. 126. The shank *A* fits the hole in the turret, while the die-holder *B* has a stem that fits the hole in the shank. While the die is cutting, the pins *D* and *C* are engaged, thus preventing the holder *B* from turning. When the turret slide of the screw machine has traveled to its limit, the holder is drawn out of the shank until the machine is reversed, when the pins engage on their opposite sides. A pin is put through the stem of the holder at *E*; this strikes the end of the shank just at the time the pins *D* and *C* become disengaged.

Both shank and body may be made of machinery steel; the shank may be finished to size, except the portion marked *A*, which should be left .010 inch large for grinding. The front end of the hole should be rounded as shown in Fig. 126, to allow fillet in the shoulder of the stem to enter. This fillet is left for strength. The pin-hole should be drilled and reamed. When the holders are to take dies not over $\frac{1}{8}$ inch in size, this pin-hole may be $\frac{3}{16}$ inch diameter; from $\frac{1}{8}$ to $\frac{5}{16}$ in size, $\frac{1}{4}$ inch diameter. As the dies increase in size, the pin must increase proportionately. The shank may be case-hardened in a mixture of granulated charred leather and charcoal; it should run about two hours, and then he dipped in a bath of oil. The hole should

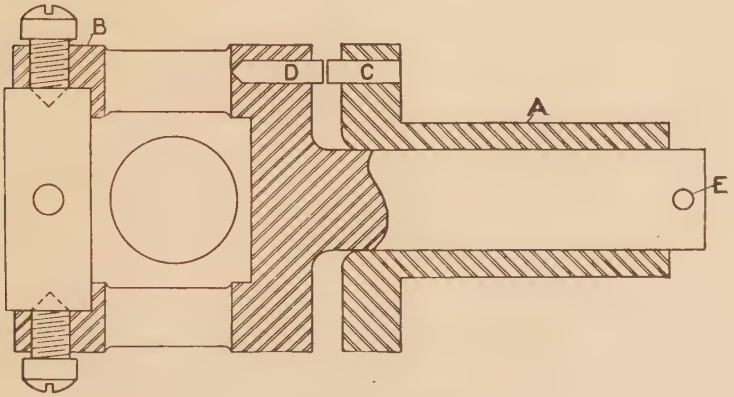

Fig. 126. Die Holder.

be lapped straight and true, and the outside ground to fit the hole in the turret. The pin *C* should be of tool steel; hardened and drawn to a blue color, and forced into place.

The holder *B* may be made from a forging, or turned from a solid piece. After roughing to size somewhat larger than finish, the stem may be turned and fitted to the hole in the shank; it should turn freely in the shank. The larger portion (or body) should now be turned to size. This should be run in the steady rest, and the end drilled and bored for the die and for clearance back of the die, as shown in Fig. 126. Three or four large holes should be drilled into the clearance hole in order that the chips and oil may find a way of escape, thus preventing injury to the threads of a screw long enough to reach through the die when being threaded.

Screw-holes should be drilled and tapped as shown in Fig. 126; the screws are to hold the die in position in the holder, and also to adjust to size, dies that are split. The stem may be placed in the shank, and the pin-hole transferred through the pin-hole in the shank into the body; this should be done before the pin *C* is pressed into place. The pin *D* should be hardened the same as *C*. The pin-hole for the pin *E* should be drilled in a location that allows *C* and *D* to become disengaged and yet have no play between the two.

Fig. 127. Flat Counterbore.

COUNTERBORES

Counterbores are used for enlarging a hole without changing its relative position. For a *hurry-up* job and for a small number of holes, it is advisable to make as cheap a form as is consistent with the work to be done. Probably the cheapest counterbore that will do satisfactory work is the flat form shown in Fig. 127. This can be forged to require but little machine work. After forging, turn to size; finish the shank *A* and pilot *B* with a fine file before taking from the lathe. The cutting edges *C C* should be faced true and smooth. The necking between the pilot and the body should be cut with a tool having the corners slightly rounded to decrease the liability to cracking when the counterbore is hardened. The flat sides *D* of the body may be finish-filed; the edges should be draw-filed, and more stock removed on the back than on the cutting edge, to prevent binding. File the cutting edges *C C* for clearance, as shown at *E*, Fig. 127. The pilot and the body should be hard the entire length, or they will wear and rough up and consequently cannot cut a smooth hole; draw the temper to a full straw color. Unless intended for accurate work, it need not be ground.

For permanent equipment, counterbores are usually made with four cutting edges, as shown in Fig. 128 and Fig. 129; Fig. 128 represents a taper shank counterbore for a taper collet, while Fig. 129 has a straight shank to be used in a chuck or collet having a straight hole the size of the shank.

Counterbores for screw-holes are usually made in sets of three—one for the head of the screw with pilot (or guide) of body size; one

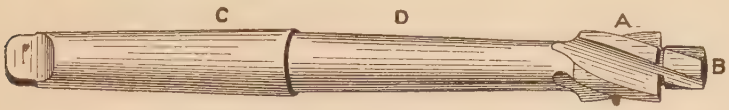

Fig. 128. Taper Shank Counterbore.

for the head with pilot of tap drill size; and one to enlarge a tap drill hole to body size.

The following instructions apply to counterbores with either straight or taper shanks. Take stock somewhat larger than finish size of counterbore. Turn a roughing chip all over the piece; turn the necked portion between the shank and body to size and stamp size of counterbore and pilot as shown in Fig. 129; turn shank *C*,

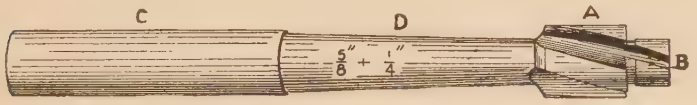

Fig. 129. Straight Shank Counterbore.

body *A*, and pilot *B* .015 to .020 inch above finish sizes, to allow for grinding. In the case of the taper shank counterbore shown in Fig. 128, the tenon should be milled. The counterbore is now ready to have the grooves milled to form the cutting edges. One method is to cut them with a right-hand spiral of from 10° to 15°; the other method is to cut the grooves straight. The former has the effect of running chips back from the cutting edges, and works very well on wrought iron and steel; while the latter method is considered more satisfactory for brass and cast iron, and also works well on wrought iron and steel. The cutting edges are given clearance by filing, as shown at *A* in Fig. 130. If the counterbore is to be used for brass,

it is necessary to give clearance to the lands also as shown at *A A A A*, Fig. 131.

When centering counterbores, or any tools whose centers are not to be used after the tool is finished, the drill should be small, and the countersinking no larger than is necessary for good results in machining. If large centers should, by accident, be put in the ends, the one

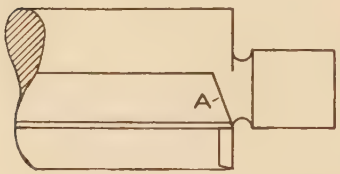

Fig. 130. Clearance of Cutting Edge.

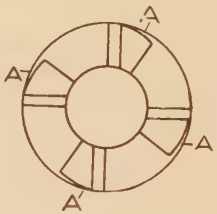

Fig. 131. Clearance of Lands.

on the end to be hardened should be filled with fire clay moistened with water to the consistency of dough, or with graphite mixed with oil; this prevents steam forming in the hole and cracking the tool when dipped in the bath. If the piece is to be heated in lead, the filling should be dried thoroughly before immersing in the red-hot lead.

Solid counterbores can be used with holes larger than the pilot by forcing a sleeve over it as shown in Fig. 132. *B* and *C* are two

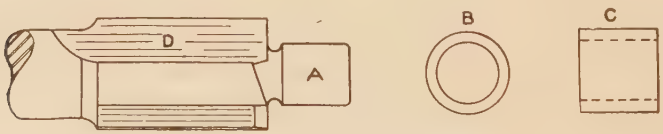

Fig. 132. Sleeve for Counterbores with Holes Larger than Pilot.

views of the sleeve which is to be forced on to the pilot *A*. After hardening, the counterbore may be ground to size on the shank, body, and pilot; the shank should be ground first, as the length is greater, and, in the case of a counterbore having a straight shank, the grinder may be adjusted to perfect alignment by measurement.

Two lipped counterbores are sharpened by grinding on the flat faces marked *D*, Fig 127. Grind a four-lipped counterbore on the flat side of the groove, as *D* in Fig. 132.

Facing Tool with Inserted Cutter. Where a limited number of holes are to be counterbored, the tool shown in Fig. 133 may be made. All that is necessary in making this tool is a piece of stock *A* the size of the hole to be counterbored, and a piece of drill rod for the cutter *B*; this may be filed to a cutting edge, hardened, and driven in

Fig. 133. Facing Tool with Inserted Cutter.

place. If accuracy is essential, a piece of drill rod must be cut off somewhat longer than the diameter of the required hole; it should be driven into the hole in the bar leaving an equal length on each side. It may be turned to the correct diameter and filed to shape. If several cutters are to be used in the same bar, or if the tool is to be used as a facing bar, to square a shoulder inside a piece of work as shown in Fig. 134, the cutter *B* is removed from the bar; and after the bar is in place, it is inserted and held by set screw *C*.

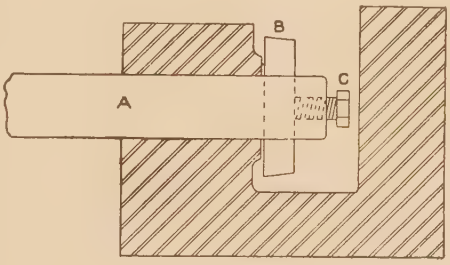

Fig. 134. Facing Bar.

For large work, a counterbore may be made as shown in Fig. 135, *A* being the cutter bar which should be made of tool steel $\frac{1}{16}$ to $\frac{1}{8}$ inch larger than finish size. After taking a roughing chip, leaving it a trifle large, the slot should be made to receive the cutter *C*. This is done by drilling a series of holes as shown in Fig. 136. After prick-punching the bar, it should be clamped to a drill-press table, holding the bar in a pair of V-blocks. The prick-punch marks should be set in a position that will insure the drill-holes going through the center of the bar. This can be done as follows: place the square against one side of the bar; measure to the center; then place the square against the opposite side, and measure in the same manner. When the dis-

tance is the same on each side from the square blade to the centers, the piece is in the proper position for drilling. The drill-press table may then be swung around until the prick-punch marks are in proper location with the spindle of the press. After drilling, a drift may be driven through to break the walls separating the holes, and the slot filed to size. The bar should be placed with one end in the steady rest,

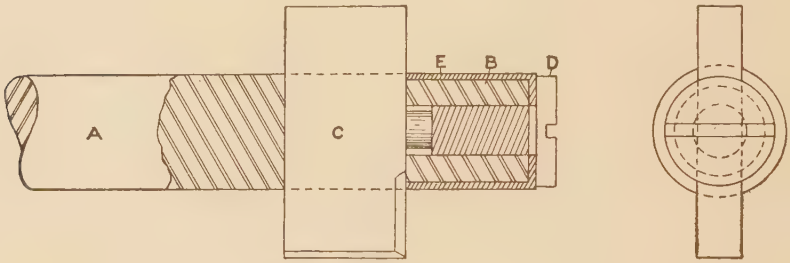

Fig. 135. Counterbore for Large Work.

and the other end strapped to the head center of the lathe. The screw-hole in the end is now drilled and tapped into the slot, in order that the screw may bind the cutter. The end should be countersunk to provide a center for finish turning. The bar may be turned to size at A, and the pilot finished to size. The screw *D* should have a head $\frac{1}{16}$ inch larger than the part *B*, in order that it may hold the

Fig. 136. Making Slot for Cutter.

sleeve in place should it have a tendency to come off when removing the counterbore from the hole. The cutter *C* should be a close fit in the slot. A headless screw should be made short, so that it will not interfere with the dead center of the lathe when it is screwed to place against the cutter blank. It is intended to be used when turning the cutter to the right diameter, and should be kept for that purpose.

Counterbores with Inserted Pilots. These are useful when the counterbores need frequent sharpening, or when a variety of different-sized holes are to be counterbored to the same size. A common form of counterbore having an inserted pilot is shown in Fig. 137.

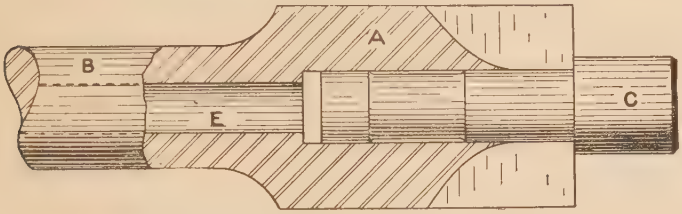

Fig. 137. Counterbore with Inserted Pilot.

When making this counterbore, the stock should have a roughing chip taken off, and the hole *E* drilled part way from the shank end. This drilling may be done in the speed lathe, holding the drill in a chuck in the head spindle; the center in the opposite end of the piece should be on the dead center of the lathe. If the piece is turned one-half revolution occasionally, the drill will cut accurately enough, as perfect alignment is not necessary in this hole, since it is intended only for use when driving out the pilot.

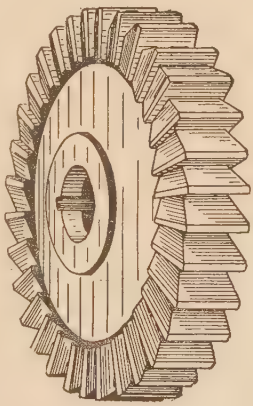

Fig. 138. Cutter for Counterbore.

After drilling, the shank end should be carefully countersunk. The piece may now be turned to grinding size, which should be from .015 to .020 inch over size all over. After turning the outside, the hole for the pilot may be drilled and bored, the large end of the counterbore running in the steady rest. The counterbore should have four cutting edges for all ordinary work; these may be cut with a side milling cutter with a face sufficiently wide to cover the width of tooth. The form of cutter is shown in Fig. 138, while an end view of the teeth is shown in Fig. 139. When milling the teeth, the counterbore can best be held in the chuck on the spiral head. If a more stubbed form of tooth is needed than the one shown in Fig. 137, the spiral head may

be tipped to the desired angle and the cutter fed through, instead of sunk into, the counterbore. After milling, the burs should be removed, and the counterbore stamped and hardened. While hardening, it should be heated to a red nearly the whole length of body; when dipped in the bath, it should be inverted in order that the teeth may be uppermost; it should then be worked up and down rapidly in the bath until the red has entirely disappeared, and allowed to remain in the bath until cold. If larger than 1 inch diameter, the strain should be removed immediately upon taking from the bath by

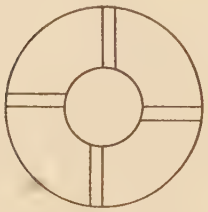

Fig. 139. End View of Teeth.

Fig. 140. Pilot for Counterbore.

heating over the fire as already explained. The pilot should be turned as shown in Fig. 140. *A* and *B B* should be left about .010 inch large for grinding after hardening; *C* should be turned $\frac{1}{32}$ inch smaller than the hole in the mill, as this does not bear when the pilot is in place. A slight depression should be made between the head and the first bearing point *B* for the emery wheel to pass over when grinding. When hardening, *A* is the only part that needs to be hard, but, unless a piece of tube is slipped over the stem *B* when the pilot is put in the bath, it will be almost impossible to harden *A* the entire length and leave *B* soft. As *A* is likely to rough up when used, it is

Fig. 141. Cover for Pilot when Hardening.

best to harden a short distance on the stem *B*, unless there should be a great difference in size between *A* and *B*. In this case a tube, or a piece of iron with a hole drilled in the end the size of *B* and having the end beveled as shown in Fig. 141, should be slipped over *B* when

the pilot is heated. This cover should be slipped over the stem and up against the shoulder of the head to prevent a *water line*; if this precaution is taken, there is no danger of the pilot cracking under the head. After hardening and tempering, the pilot may be ground to size at A, and the portions $B\,B$ ground to fit the hole of the counterbore. After grinding, the pilot may be forced into place. The counterbore may be ground with the pilot in position. When the counterbore is dull, the pilot should be forced out of it and the cutting edges ground with an emery wheel.

Combination Counterbores. These are made when it is necessary to change the size of counterbore and pilot frequently. A shank or bar is made to accommodate different sizes of cutters, and sleeves serve as pilots. In Fig. 142, A is the cutter, and B the pilot

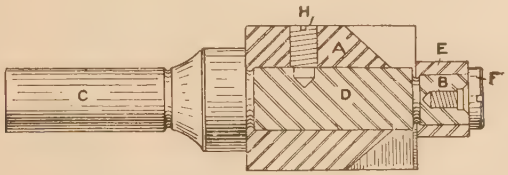

Fig. 142. Combination Counterbore.

which is tapped in the end to receive a screw to hold the sleeves, and C is the shank which is held in a chuck or collet, when the counterbore is in use.

After taking a roughing chip off the bar, the end B is run in the steady rest and the hole for the screw F is drilled and tapped. The outside end is countersunk to a 60° angle to run on a center. When machining the holder, the portions B, C, and D should be left about .010 inch larger than finish size, to allow for grinding. But if no grinder is at hand, they may be left a few thousandths of an inch above size, and filed to finish dimensions.

The body (or cutter) A, should have a hole $\frac{1}{16}$ inch smaller than finish size drilled through it; the outside surface should be turned off, and the piece annealed. If a grinder having an internal grinding attachment is at hand, the hole in the cutter should be left .005 inch small for grinding. If such an attachment is not at hand, the hole may be reamed to finish size. The outside diameter should be left about .010 large; the ends should be faced to length, and the teeth

cut. If four teeth are to be cut, the work may be done with the side milling cutter, shown in Fig. 138. The counterbore should be held in a chuck on the spiral head spindle, which should be tipped to produce a strong tooth, as shown in Fig. 142. Before hardening, the hole should be drilled and tapped for the screw *H*, which holds the counterbore to the bar. To harden, the counterbore should be given an even, low, red heat, and plunged in water or brine in such a manner that the bath will come in contact with the teeth. If the teeth are stubbed and strong, the temper need not be drawn more than to a light straw color.

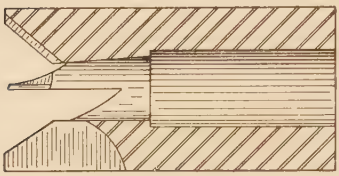

Fig. 143. Hollow Mill with "V" End.

The screw *H* should be made of tool steel and have a projection

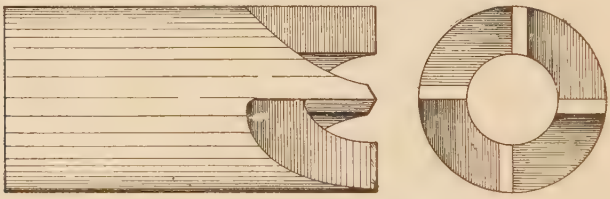

Fig. 144. Hollow Mill for Squaring Up Shoulder.

$\frac{1}{8}$ inch long on one end, turned to the bottom of the thread. This is to enter a hole drilled in the bar or holder, and keep the counterbore from turning. The end of the screw should be about .005 inch smaller than the hole. The screw should be hardened and drawn to a blue color. The sleeve intended to go on the pilot *E* should be made of tool steel, hardened and ground to size inside and out. The screw *F* may be made of machine steel, and case-hardened sufficiently deep, by heating to a red and sprinkling with powdered cyanide of potassium, after which it is reheated and plunged in water.

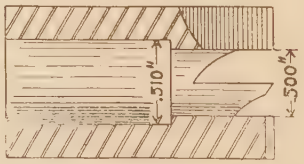

Fig. 145. Mill with Edges Filed.

HOLLOW MILLS

Hollow mills are used in screw machines and turret lathes for roughing down and finishing. They are also used in drill-press work in finishing a projection which must be in some given position; when thus used, they are generally guided by a bushing in a fixture, to bring the projection in the proper location.

For roughing out work on a screw machine or turret lathe, solid mills having strong stubbed teeth are preferred for rigidity. For finishing, they are made adjustable in order to get *exact* sizes. Fig. 143 shows a solid hollow mill having the cutting end hollowed out in the form of a V, in order that it may center itself when starting to cut. Fig. 144 shows a form of solid hollow mill intended for use in squaring up a shoulder at the end of a cut that has been made with a mill of the form shown in Fig. 143, or it may be used for roughing

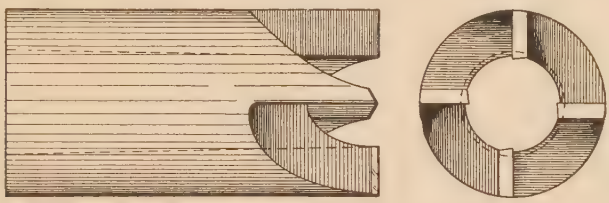

Fig. 146. Hollow Mill with Tapered Hole.

out a piece; however, it will not center itself as readily as the one shown in Fig. 143. For small hollow mills, some tool-makers advocate three cutting teeth, while others claim better results with four teeth on all sizes.

The rear end of the mill is bored somewhat larger than the cutting end, to allow it to clear on long cuts. The cutting end must be relieved, or it will bind and rough the work, and probably twist it off in the mill. There are several methods of relieving mills; the more common one is to ream the hole tapering, making it larger at the back end, as shown in Fig. 146. Another method is to file back of the edges, as shown in Fig. 145.

For making hollow mills having the same outside diameter, it is advisable to use a holder of the form shown in Fig. 147, having a taper shank which fits the spindle of a lathe. The hole in the other end of the holder should be the size of the holder in the screw machine

or turret lathe, which holds the mills when in use. The steel for the hollow mills should be cut to length, and turned to the proper diameter to fit the holder. After putting the blank in the holder, the ends may be squared, and the holes drilled and bored to the desired sizes. If the mill is to be of the form shown in Figs. 143, 144, and 145, the cutting end may be reamed with a taper reamer to give the neces-

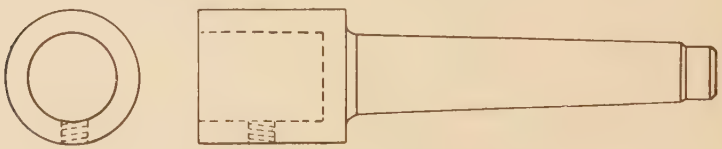

Fig. 147. Holder for Hollow Mills.

sary clearance. The reamer should be run in from the back end in order that this end of the hole may be larger. For the form shown in Fig. 146, the hole at the cutting end should be straight and to finish size.

The mill is now ready for cutting the teeth. If four cutting edges are to be given, a side milling cutter may be used, of a diameter about double the diameter of the hollow mill to be cut. The blank should be held in a chuck on the end of the spindle in the spiral

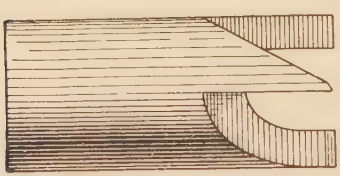

Fig. 148. A Strong Tooth.

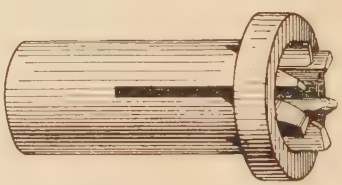

Fig. 149. Adjustable Mill.

head. For a strong tooth, the spiral head may be set at an angle that will produce a tooth as shown in Fig. 148, by feeding the milling cutter *through* the blank. If a deeper tooth is desired, the spiral head may be set so that the blank will be in a vertical position, and the milling cutter fed in until the desired form and depth of tooth are obtained.

Adjustable Hollow Mills. These may be made by following the instructions given for solid hollow mills, except that the mill must be split as shown in Fig. 149, in order that the size of hole in the

mill may be altered. There are two methods of adjusting the mill. The outside of the cutting end of the mill is tapered, and a collar having a corresponding taper hole is forced on the mill. The collar closes it, and causes it to cut smaller. The other method is to turn the outside of the hollow mill straight, and close by means of the clamp collar shown in Fig. 150. As adjustable hollow mills are generally used for finishing cuts, and are not used when taking heavy cuts, the teeth may be made finer than those of solid mills used for roughing. The teeth, being nearer together, will finish a cylindrical piece more accurately than if the teeth were cut farther apart. It is customary to give adjustable hollow mills, to be used for finishing, from six to eight teeth. The cutting edges should be radial for most work. Better results will be obtained if the hole in the cutting end of the mill is left .005 inch small, and ground to size after the mill is hardened.

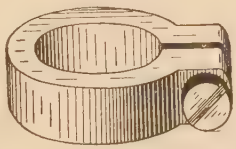

Fig. 150. Clamp Collar.

The hollow mill, whether it be solid or adjustable, should be hardened a trifle farther up than the length of the teeth, and drawn to a straw color. The mill is sharpened by grinding on the ends of the teeth.

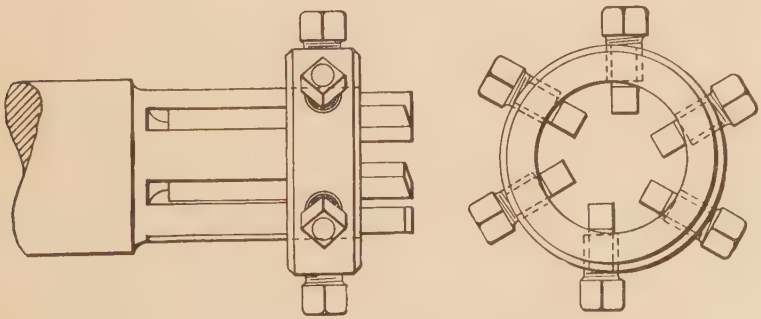

Fig. 151. Hollow Mill with Removable Blades.

Hollow Mill with Inserted Blades. For large work, hollow mills are made with inserted blades. The hollow mill with removable blades, shown in Fig. 151, does good service on rough work; the blades may be made of self-hardening steel and inserted in a machine steel body. The grooves in the body, to receive the blades, should be

milled with a cutter whose thickness corresponds to the size of the steel to be used for the blades. The grooves are cut somewhat deeper at the front end of the holder, in order that the blades may have clearance to prevent binding. The edge of the slot corresponding to the cutting edge of the blade should be radial.

Two collars should be made of machine steel, having holes sufficiently large to allow their being placed on the mill when the blades are in the slots. Each collar should be provided with the same number of set screws as there are blades in the mill. One collar holds the blades in the holder, while the other is placed nearly at the ends of the blades to support them while cutting. This form of mill is used on cuts not exceeding one inch in length, as the blades must project beyond the holder to the desired length of the cut.

The size of cut may be changed somewhat by setting the cutters back or ahead in the slots, or paper may be placed in the slots under

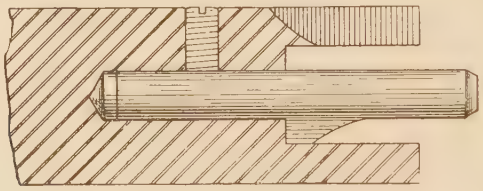

Fig. 152. Hollow Mill with Pilot.

the blades to increase the diameter of the cut. The blades are set to an even length by bringing them against a surface perpendicular to the axis of the body of the tool.

Hollow Mill with Pilot. It is often desirable to mill the outside of a projection central with a hole passing through it. This may be done very satisfactorily with a hollow mill having a pilot, as shown in Fig. 152. It is advisable to hold the pilot in place by means of a set screw. In order to give clearance to the teeth to prevent the mill binding when cutting, the hole may be bored tapering .010 inch in $\frac{1}{2}$ inch of length, making it largest at the back end.

When hardening a mill of this description, it is advisable to dip it in the bath with the cutting end uppermost, working it up and down rapidly. After hardening, it may be drawn to a straw color. The pilot should be turned .010 inch above finish size, hardened, and drawn to a brown color, and ground to the desired dimensions.

At times it is necessary or desirable to use a hollow mill as a counterbore; that is, it is necessary to enlarge a hole all the way through a piece of stock. As the core removed would bind and stick in the hole in the mill, the hole is made eccentric, as shown in Fig. 153. The pilot is concentric with the outside, and should

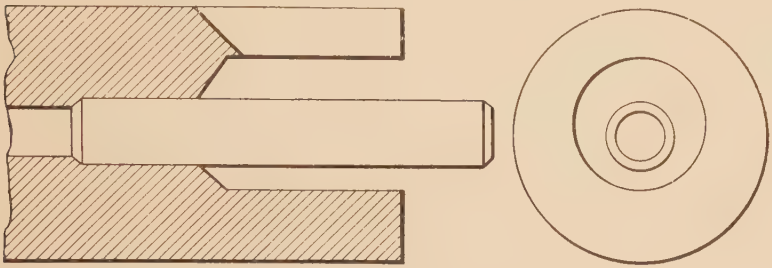

Fig. 153. Hollow Mill with Eccentric Pilot for Use as Counterbore.

not be a *tight* fit in the hole to be enlarged. The core removed will be smaller than the hole in the mill, and consequently will not bind.

FORMING TOOLS

Forming tools are used when several pieces are to be made of exactly the same shape. They are particularly valuable for giving the desired shape to formed mills and similar tools, and are extensively used in duplicating a given shape on work produced in the screw machine.

Forming tools are made flat and circular in shape. When used in the lathe for shaping milling-machine cutters and similar tools, they are generally made flat; for backing off formed milling-machine cutters, they are always made flat; for screw machines in duplicating a given shape, they are made both flat and circular.

The flat forming tool is made as a solid cutter, the tool and shank being in one piece, as shown in Fig. 154; or the cutter and shank may be made separate, as shown in Fig. 155. When but one forming tool is to be made, that shown in Fig. 154 will be found to be inexpensive; but for making many tools, it will be found much cheaper to adopt the plan shown in Fig. 155.

On certain classes of work, it is advisable to use a forming tool on a holder of the description shown in Fig. 156, which is known as a

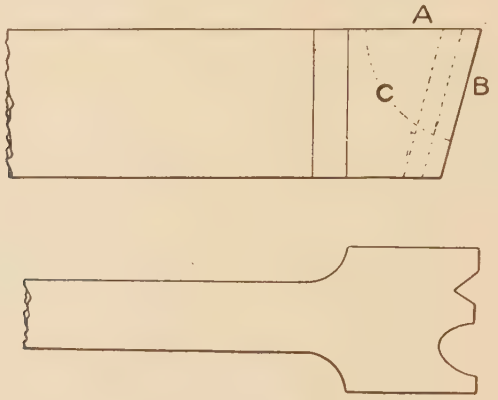

Fig. 154. Flat Forming Tool.

spring-holder. On account of its design, it may spring somewhat when used on heavy cuts, thus reducing the tendency to chatter. It is necessary to make these holders of tool steel, giving them a spring

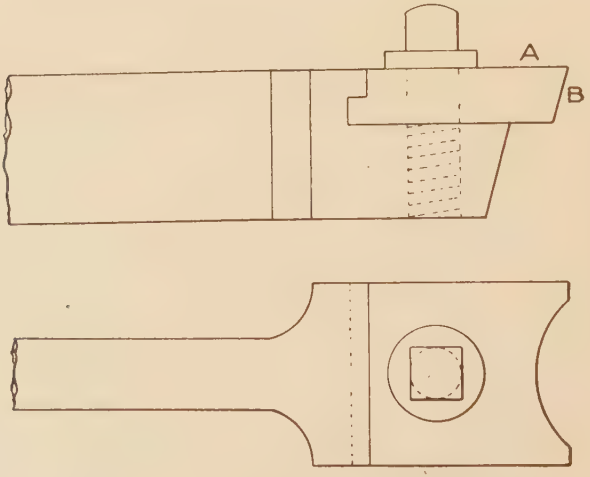

Fig. 155. Forming Tool with Separate Shank.

temper at point marked *A*. The slot *B* allows the forming blade *D* to spring away from the work when under heavy strain. The blades may be planed up in long strips and cut off the required length. The

tongue *E* should fit the slot *C*, which, with two cap screws through *F* and *G*, securely holds the blade in position.

In order that a forming tool may cut readily, it is necessary to give the surface marked *B* (Fig. 155) a sufficient amount of clearance. For tools to be used for shaping milling-machine cutters and similar tools,

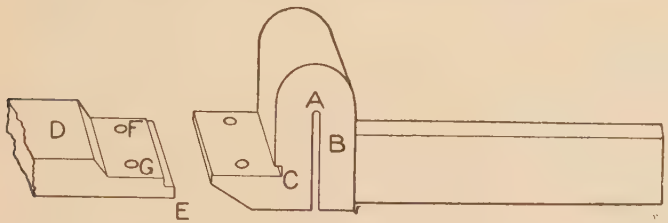

Fig. 156. Spring Forming Tool Holder.

a clearance of 10° to 15° will be ample; that is, the angle should be from 80° to 75°. But if the tool is to be used for backing off the teeth of formed milling-machine cutters, it is necessary to give a clearance of 18° to 22°. When making a forming tool having the required angle at *B*, the shape can be produced by tipping the blank to the required angle and planing or milling with a tool having exactly the shape it is desired to produce. The tool used may be made of a shape enough different from that desired that it may produce the proper shape when the cutter is in a vertical position, and the blank at a given angle from that position, as shown in Fig. 157. Or, the tool may be held in the tool-post (or in a fixture made for the purpose) of the shaper or planer at the same angle as the blank being cut, as shown in Fig. 158, and it will produce a shape corresponding very closely with its own.

Fig. 157. Making Tool with Cutter at an Angle.

Fig. 158. Tool with Cutter Vertical.

For screw-machine and similar work for duplicating given shapes, a forming tool is made of the shape shown in Fig. 159. *A* represents a holder used by the Brown & Sharpe Mfg. Co. for use on

their screw machines. *B* shows the forming tool blank. The desired shape is cut in the surface marked *C*.

Circular Forming Tools. These are used very extensively on screw-machine and similar work. They are valuable on account of the ease with which any number of them may be produced, pro-

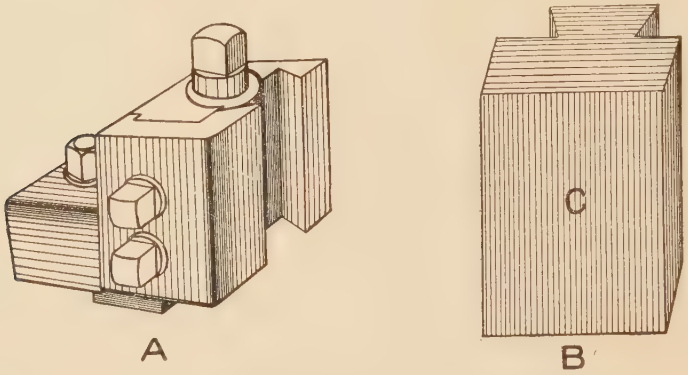

Fig. 159. Forming Tool for Duplicating Shapes.

vided a forming tool is used in producing the shape on the face, as shown in Fig. 160. After the blank has been formed to the desired shape, it may be milled as shown in Fig.161, in order to provide a cutting edge. If it is desired to produce a shape on the piece being machined, to correspond with the shape of tool, it is necessary to

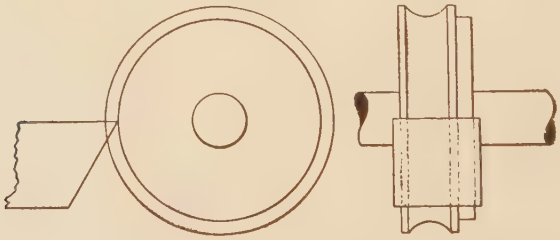

Fig. 160. Straight Forming Tool Producing Circular Tool.

have the cutting edge radial as shown in Fig. 161. In order to feed the tool into the stock faster than can be done with the form shown in Fig. 161, it is given more clearance, as shown in Fig. 162. On a tool whose cutting edge is not radial and will not produce a shape corresponding to its own, it is necessary, when cutting the edge with

the rake shown in Fig. 162, to make the face of the tool slightly different in form from that desired.

After milling the cutting edge, the name or number of the tool may be stamped on it, after which it is ready for hardening. When extremely high carbon steel is used, the tools sometimes crack while

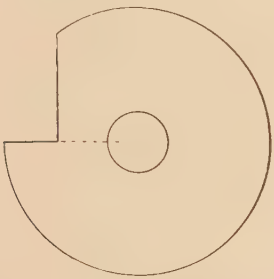

Fig. 161. Radial Cutting Edge.

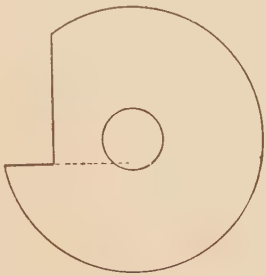

Fig. 162. Offset Cutting Edge.

hardening, from the strain incident to their shape. In order to overcome this tendency, some tool-makers make two extra cuts in the edge, as shown in Fig. 163, in order that the hardened edges may not be cracked from the contraction. Two cutting edges, as shown in Fig. 164, are often given a tool in order that it may not need to be

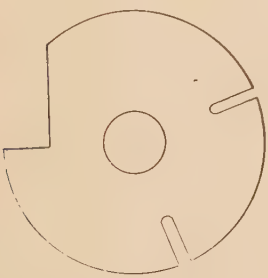

Fig. 163. Cuts to Prevent Contraction Cracks.

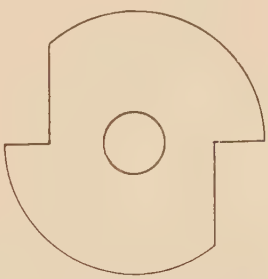

Fig. 164. Double Cutting Edge.

ground as often as when it has but one cutting edge. It is not necessary to stop the screw machine nearly as long to grind both cutting edges, as to stop the machine twice to grind the same edge, on account of the time necessary to rig up the grinder.

When hardening, the tool should be heated to a low red, and plunged in a bath of water or brine from which the chill has been

removed; it should be worked around well in the bath. If the temper is not to be drawn after hardening, the tool may be held over the fire after removal from the bath, and heated sufficiently to remove the tendency to crack from internal strains.

On account of some weak projection, which, because of its shape, is likely to break when used, it is sometimes necessary to draw the temper. It is not always necessary to draw the temper to a straw color, and as a light straw is the first temper color visible, some other means must be employed. The tool may be placed in a kettle of oil, and by means of a thermometer any degree of heat may be obtained. The writer recalls a certain forming tool which was too brittle when left as it came from the hardening bath, yet was not hard enough when drawn to even the faintest straw color. When taken from the harden-

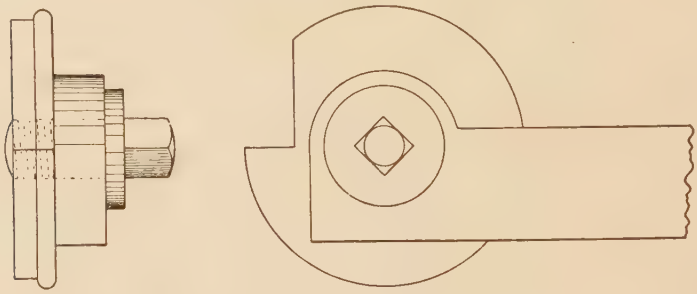

Fig. 165. Tool Holder for Hand Screw Machine.

ing bath, it was placed in a kettle of boiling water and left there about five minutes. The heat of the water at 212° reduced the brittleness so that the tool stood up in good shape, yet it did not perceptibly soften it.

The following is an excellent plan: Use a bath of water having about one inch of oil on top; the tool after being heated red-hot is plunged down through the oil into the water. Enough oil adheres to prevent the sudden shock which the steel would receive if plunged directly into cold water. Pack-hardening also gives excellent results.

Tool-Holders. The form of the holder for the tool depends on the class of work to be done and the machine in which it is to be used. Fig. 165 shows a design commonly used for hand screw machine work. If the cuts are comparatively light, the side of the tool and

holder may be flat as shown. If, however, heavy cuts are taken which would have a tendency to turn the tool, it is often made with a taper projection on one side, as shown in Fig. 166, the holder having a corresponding taper hole to receive the projection. This projection should be a good fit in the taper hole, but should not go in far enough to strike the bottom, neither should the side of the tool bear against the side of the holder.

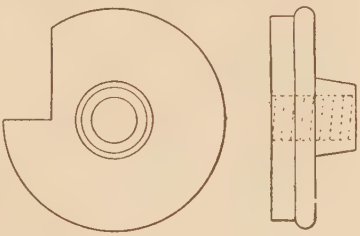

Fig. 166. Tool for Heavy Cuts.

When used in automatic screw machines, the holder is generally of a different shape from that used for hand screw machines. A very common form is shown in Fig. 167. This holder is made in the form of an angle iron. The fixture (holder) is fastened to the tool-rest by means of the bolt shown. The tool is fastened to the upright side of the holder by means of the bolt represented, with its head let into the forming tool.

When extra heavy cuts are to be taken with a forming tool, it is

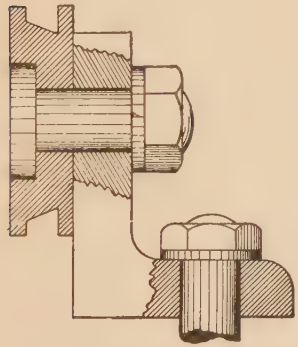

Fig. 167. Holder for Automatic Screw Machines.

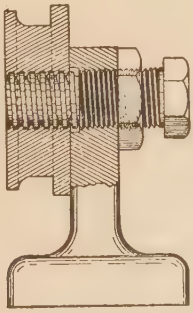

Fig. 168. Holder for Heavy Cuts on Automatic Machines.

sometimes considered advisable to make a holder of the form shown in Fig. 168. The holder is bolted to the tool-rest in the same manner as the one represented in Fig. 167. A square thread having a pitch of five or six threads to the inch is cut in the forming tool; the thread should be right- or left-hand, depending on which side of the machine the tool is to be located when in use, the thread being such that the

tool will tighten by the pressure exerted by the cut. To get an adjustment, the thread in the holder must be of a finer pitch than that in the forming tool, and of the same hand. If desired, this tool may be used in the ordinary form of holder shown in Fig. 167 by use of the bolt shown in Fig. 169.

Fig. 169. Adapting Bolt.

At times it is necessary to use two forming tools; these may be arranged to meet the requirements of the individual job. In Fig. 170 are shown two forming tools arranged to cut a desired shape.

At the present time when high-speed steel is so extensively used in reducing the cost of many machine operations, forming tools are made from this metal. And while they may be hardened by heating in specially constructed furnaces, or in a crucible of red-hot lead, and then dipping in oil, more satisfactory results are obtained if they are pack-hardened by the method described under "Pack-Hardening High-Speed Steel."

After pack-hardening the tool, it may be necessary to draw the temper somewhat; this will not be necessary if the tool is strong, and is not to be subjected to severe use. If, however, the tool is weak or has weak projections, it will be found necessary.

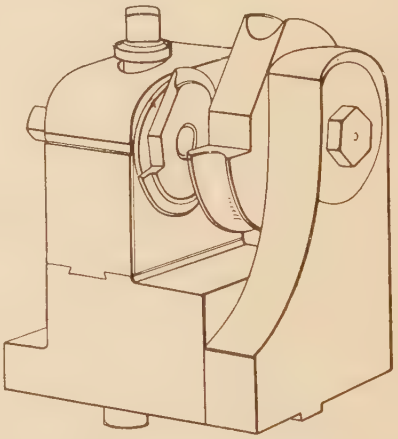

Fig. 170. Arrangement of Two Forming Tools for Special Work.

MILLING CUTTERS

Milling-machine cutters are made in two different forms—*solid* and *with inserted teeth.* It is customary in most shops to make cutters up to 6 or 8 inches in diameter solid, and above this size they are made with inserted teeth.

At the present time, when rapid reduction of stock is necessary, it is the custom in many shops to make many of the milling-machine cutters from high-speed steel. If this steel is properly annealed, it is easily worked to shape; but much better results are obtained if the

tools used in cutting it, both in the lathe and milling machine, are made from high-speed steel.

Milling cutters made from this steel may be heated for hardening in a specially designed furnace or in white-hot lead; but, if so treated, they must first be pre-heated in an ordinary fire to a low red heat, as the sudden expansion due to rapid heating would rupture the steel and spoil a valuable tool. When it is uniformly heated to the proper temperature, plunge it in raw linseed oil or in fish oil.

Much more satisfactory results are obtained if the cutters are pack-hardened as described under "Pack-Hardening High-Speed Steel."

Although many shops have adopted high-speed steel for most of their milling cutters, and some shops use nothing else, yet many mechanics claim that for cutters of intricate form and which must retain a fine finishing edge, high-carbon steel gives better results. While they use the latter steel for cutters of the description mentioned, yet, for all roughing cutters and for those of ordinary form where *fineness* of cutting edge is not material, they use high-speed steel.

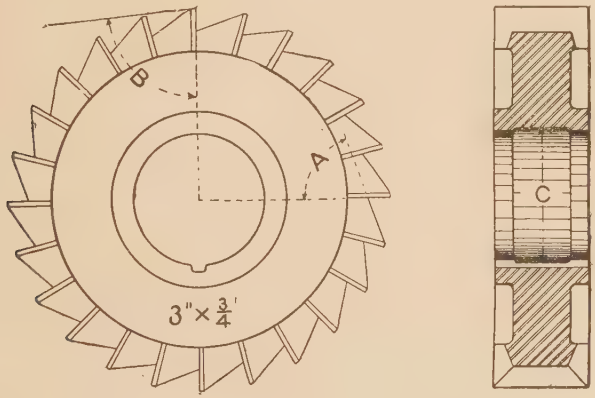

Fig. 171. Side Milling Cutter.

Solid Cutters. When making solid cutters, it is advisable to use steel somewhat larger than the finish diameter of the cutter. A hole should be drilled in the blank $\frac{1}{16}$ inch smaller than the finish size of the hole, and the outside surface should be turned off. After annealing, the blank should be put in the chuck on the lathe, the hole bored, reamed to size, and recessed as shown at *C* in the sectional view of Fig. 171.

The piece should now be placed on the mandrel, and turned to the proper diameter and length. The teeth should be cut in the universal milling machine, or in a milling machine provided with a pair of index centers. The number of cutting edges for solid milling cutters varies somewhat according to the nature of the work to be done, but for general shop use Table VIII will be found satisfactory.

TABLE VIII

Cutting Edges for Milling Cutters

Diameter of Cutter	No. of Cutting Edges	Diameter of Cutter	No. of Cutting Edges
$\frac{1}{2}$ in.	6	$2\frac{1}{2}$ in.	20
$\frac{3}{4}$ "	8	3 "	24
1 "	10 or 12	$3\frac{1}{2}$ "	26
$1\frac{1}{4}$ "	14	4 "	28
$1\frac{1}{2}$ "	16	5 "	30
2 "	18	6 "	32

For most work it is desirable to have the faces of the teeth radial, as shown in Fig. 171. However, when milling cutters are made to run in the direction of the feed or onto the work instead of against it, the teeth should be given a negative rake (cut ahead of the center) as shown in Fig. 172, as this has a tendency to keep the piece being milled from drawing toward the cutters.

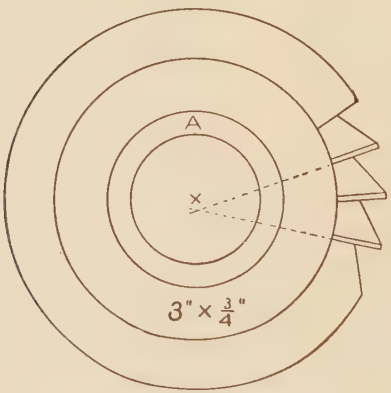

Fig. 172. Cutter with Negative Rake.

When cutting the teeth, it is necessary to use a cutter that gives sufficient depth of tooth to provide a receptacle for chips, and also gives a form that supports the cutting edges. A cutter may be used that will produce an angle of about 50° between the face and back of the tooth as shown at *A* in Fig. 171. The cutter should cut deep enough to leave the lands about $\frac{1}{32}$ inch in width at the cutting edges.

The form of cutter shown in Fig. 171 is known as a *Side Milling Cutter*. When cutting teeth on the sides, it is necessary to put the cutter on a plug whose upper end does not project much above the top face of the cutter; this plug may be made straight and held in the chuck on the end of spindle in the spiral head. Such a plug is shown in Fig. 173, inserted in the cutter. If many cutters are made with teeth on the sides, it is advisable to make an expanding arbor, Fig. 174, whose shank fits the taper hole in the spindle of the spiral head. When milling the teeth on the sides, the index head must be inclined a little so that the side of the mill will stand at a small angle from the horizontal in order that the lands of the teeth may be of equal width at each end. The amount of this inclination cannot readily be computed. It is formed by first cutting a tooth, leaving the cut somewhat shallow, then turning to the next tooth. After cutting the second tooth, the change in inclination will be apparent.

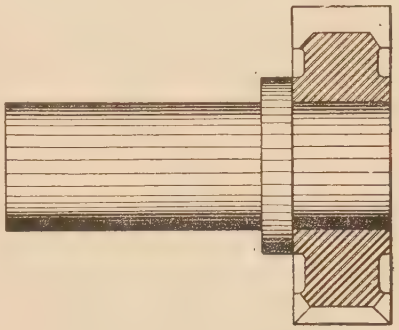

Fig. 173. Cutter on Plug.

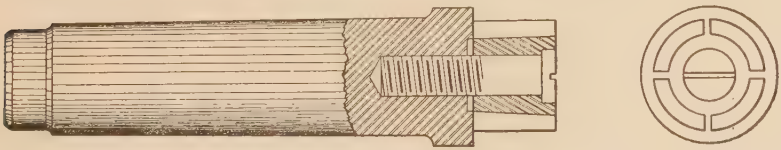

Fig. 174. Expanding Arbor.

When the teeth are cut and the burs removed, the diameter and length of the cutters may be stamped as shown in Fig. 171. The cutter is now ready for hardening. To successfully harden, it is necessary to have a low, uniform red heat; the teeth must be no hotter than the portion between the hole and the bottom of the teeth. When held toward the light, there should be no trace of black in the interior of the cutter. When a uniform heat no higher than is necessary to harden the steel has been obtained, the cutter may be plunged into brine from which the chill has been removed; it should be worked

around rapidly in the bath until the singing has ceased. It should then be removed from the brine and immediately plunged into oil and allowed to remain there until cold. When cold, the cutter may be taken from the oil and heated sufficiently to prevent cracking from internal strains. The cutter may now be brightened and the temper drawn to a straw color.

Grinding the Hole to Size. It is customary to ream the holes in milling cutters to size, and if the cutter contracts in hardening, the holes are brought to size again by lapping with a lead or cast iron

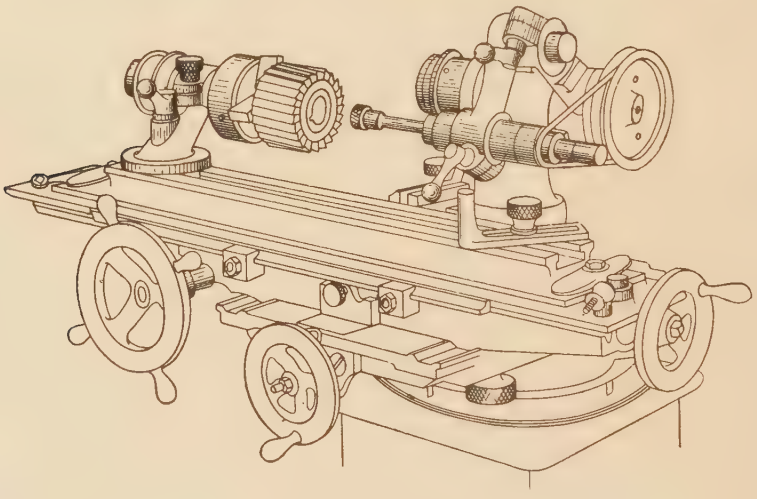

Fig. 175. Grinding the Cutter.

lap, by means of oil and emery. However, this operation does not provide for the enlarging of the hole. While this is an unusual occurrence, it *sometimes* happens; and, as a consequence, the cutter does not fit the milling-machine arbor and cannot do as good or as much work as it should.

On account of the necessity of having a correct fit on the milling-machine arbor, it is advisable to ream the hole of the cutter with a reamer about .005 inch under the size of the arbor, and finish by grinding after the cutter is hardened.

When grinding the hole to size, the cutter may be held in a chuck and ground with a small emery wheel, using the internal grinding attachment as shown in Fig. 175. This attachment is so designed

that it may be swung out of the way when gauging the size of the hole as shown in Fig. 176. After grinding the hole to size, it is advisable to grind the shoulders on each side of the cutter straight and true with the hole, in order to prevent any possibility of springing the milling-machine arbor by any untruth on the part of the cutter, and to prevent any possibility of the cutter running out of true. The shoulder (or boss) referred to is shown in *A*, Fig. 171.

There are two methods of grinding the shoulders. By one method, the outer shoulder and the hole are ground at the same set-

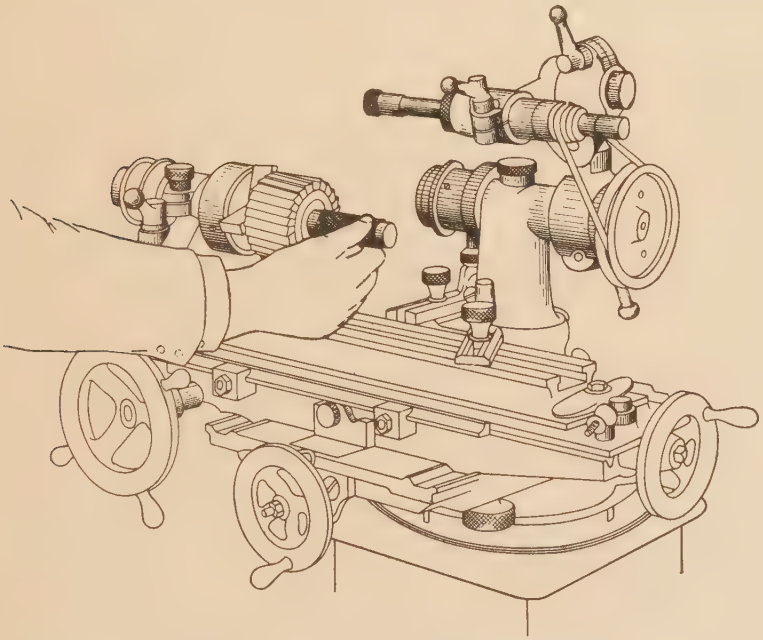

Fig. 176. Gauging Size of Hole in Cutter.

ting; if this is done properly, this shoulder will be true with the hole. The chuck is now removed from the grinder, and a face-plate having an expanding plug is put in its place. The shoulder that has been ground is placed against the face-plate, with the expanding plug in the hole of the cutter. The outer shoulder may be ground after the plug is expanded until the cutter is held rigidly in place against the face-plate, which should run perfectly true.

By the other method, both shoulders are ground while on an

arbor which is necked down each side of the cutter as shown in Fig. 177. This necking allows the wheel to traverse the whole length of the shoulder and not cut into the arbor, as would be the case if an ordinary mandrel were used.

Grinding. In order to get the best results from a milling cutter, it is necessary to use some form of grinder having a means of properly locating each tooth as it is presented to the wheel. This is usually accomplished by a finger which may be adjusted to the proper height to produce the required amount of clearance. The teeth may be given a clearance of about 3°, as shown at *B*, Fig. 171. With this amount

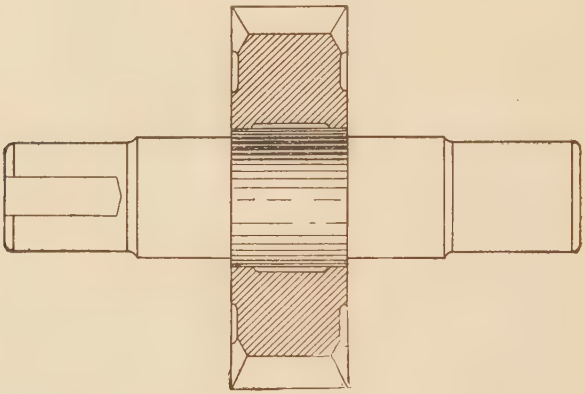

Fig. 177. Cutter Blank on Special Arbor for Grinding.

of clearance, the cutter works freely and retains its edge; if more clearance is given, the cutter is likely to chatter, and the edges of the teeth will become dull rapidly.

Fig. 178 shows a cutter in position for grinding the teeth; it will readily be seen that the tooth being ground, rests on the finger or tooth-rest; this finger may be adjusted to give any desired amount of clearance to the tooth. For grinding the teeth on the *side* of a milling cutter, a small emery wheel may be used in order to get the necessary amount of clearance without touching the tooth next to the one being ground.

If a grinder is used which will take a cup wheel as shown in Fig. 179, and whose table can be turned to bring the cutter in the position shown in Fig. 180, a form of clearance is given the tooth which is more satisfactory than if ground with a small wheel. With the cup wheel,

the line of clearance is straight; while with the small plain wheel it is hollowed out, and as a consequence the cutting edge is weak.

Spiral Milling Cutters. It is customary in most machine shops

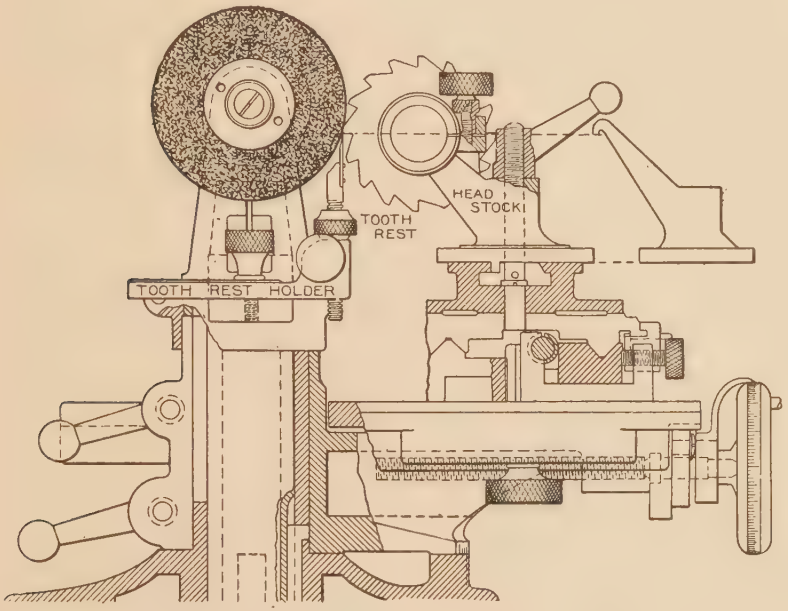

Fig. 178. Cutter in Position for Grinding the Teeth.

to make all milling cutters of more than $\frac{1}{2}$-inch face with teeth cut spirally as in Fig. 181. The amount of spiral given the teeth varies in different shops and on different classes of work.

The object of providing spiral teeth is to maintain a uniformity of cutting duty at each instant of time. With teeth parallel to the cutter axis, the tooth, on meeting the work, will take the cut its entire length at the same instant, causing a jump to the work on account of the springing of the device holding the work, and of the cutter arbor. If the teeth are cut spirally, the cut proceeds gradually along the whole length of the tooth; and after the cut is started, a uniform cutting action is

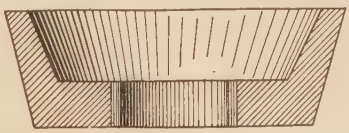

Fig. 179. Cup Wheel.

maintained, producing smoother work and a truer surface, especially in the case of wide cuts.

Milling cutters may be cut with either a right- or left-hand spiral or helix, although it is generally considered good practice to cut a mill having a wide face with a spiral that will tend to force the cutter arbor into the spindle rather than to draw it out; then again, it is better to have the cutting action force the solid shoulder against the box, rather than draw the adjusting nut against the box.

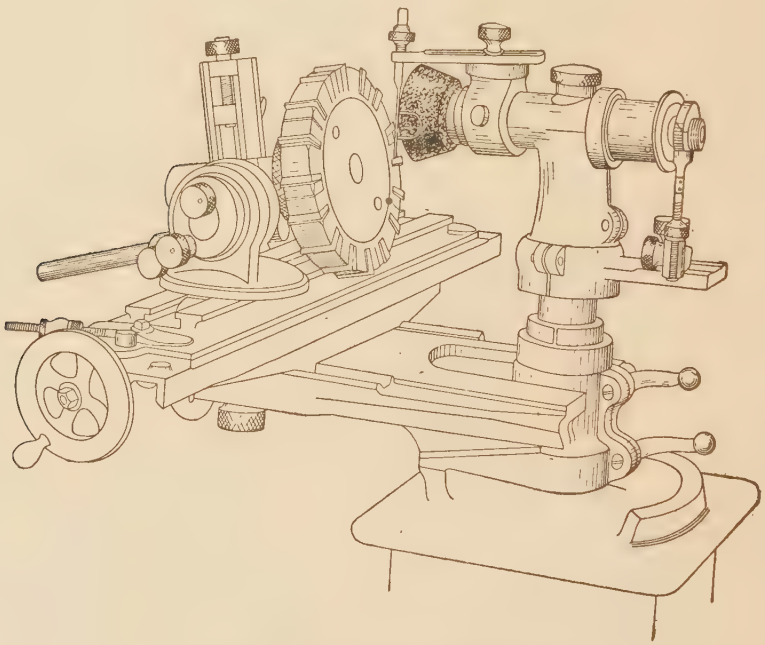

Fig. 180. Cutter Grinder with Cup Wheel.

Where two very long mills are used on the same arbor and it is found necessary to cut them with a quick spiral, one cutter is sometimes cut with a right-hand spiral and the other with a left-hand spiral in order to equalize the strain and reduce the friction resulting from the shoulder of the spindle pressing so hard against the box.

Special care should be taken in cutting spiral milling cutters, that the work does not slip. When a cut has been taken across the face of a cutter, it is best to lower the knee of the milling machine,

thus dropping the work away from the mill while coming back for another cut; the knee can then be raised to its proper position, which may be determined by means of the graduated collar on the elevating shaft of the machine.

As it is important that the face of the cutting tooth be radial and straight, it will be found necessary to use an angular cutter of the form shown in Fig. 182, as cutters of this form readily clear the

Fig. 181. Milling Cutter with Spiral Teeth

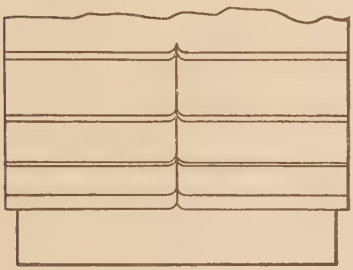

Fig. 183. Badly Made Mill.

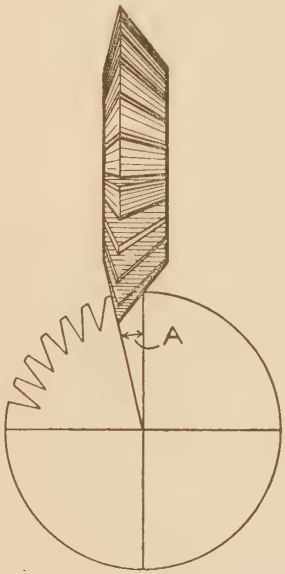

Fig. 182. Angular Cutter for Spiral Mill.

radial face of the cut and so remain sharp longer and produce a smoother surface to the face of the tooth than an angular cutter of the form used for cutting teeth which are parallel to the cutter axis.

The angular cutters for spiral mills are made with either 40°, 48°, or 53° on one side, and 12° on the other.

By setting the cutter, as shown in Fig. 182, so that the distance *A* is one-twelfth the diameter, the face cut by the 12° side of the angular cutter will be nearly radial for the usual proportions.

The setting for cutting the teeth of a spiral cutter must be made before turning the spiral bed to the angle of the spiral.

Milling Cutters with Interlocking Teeth. When two milling cutters of an equal diameter are to be used on the same arbor in such a manner that the end of one cutter is against the end of the other, the corners of the cutting teeth are likely to break away, leaving a projection—or fin—on the work, as shown in Fig. 183. In order to overcome this, part of the teeth are cut away on the sides of the cutters; that is, a tooth will be cut away on one cutter, and the corresponding tooth on the other cutter will be left full length to set into the recess formed by the cutting away of the tooth. In some shops it is customary to cut away every other tooth; while in others two, three, or four teeth will be cut away and an equal

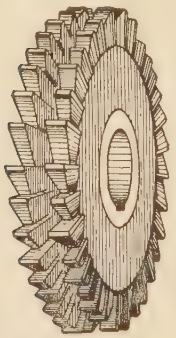

Fig. 184. Pair of Mills with Alternate Teeth Cut Away.

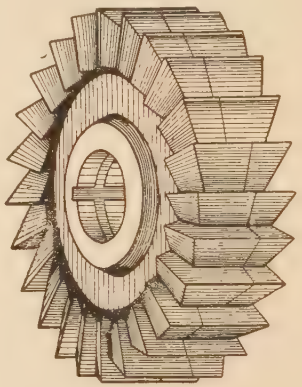

Fig. 185. Pair of Mills with Four Teeth Cut Away.

number left. Fig. 184 represents a pair of mills having every other tooth cut away, while Fig. 185 represents a pair having four teeth cut away.

In order to cut away the teeth to make the cutter of a form having interlocking teeth, the cutter should be placed on a plug or expanding arbor as described for milling teeth on sides of side-milling cutters. By means of a milling cutter having the proper width, the teeth may be milled away, although, in case of a cutter having several teeth cut away as shown in Fig. 185, it is well to use a narrow cutter, and after taking one cut, turn the index head so that the next tooth is in position. Continue doing this until the desired number of teeth are cut away. The index head may now be turned to pass over the required number of teeth, and the operation repeated.

It is necessary, when making cutters with interlocking teeth (sometimes called *dodged-teeth*), that the milling be deep enough to prevent the corresponding tooth on the other part of the cutter from striking the bottom of the recess. The parts of the cutter should bear against each other on the shoulders, or hubs.

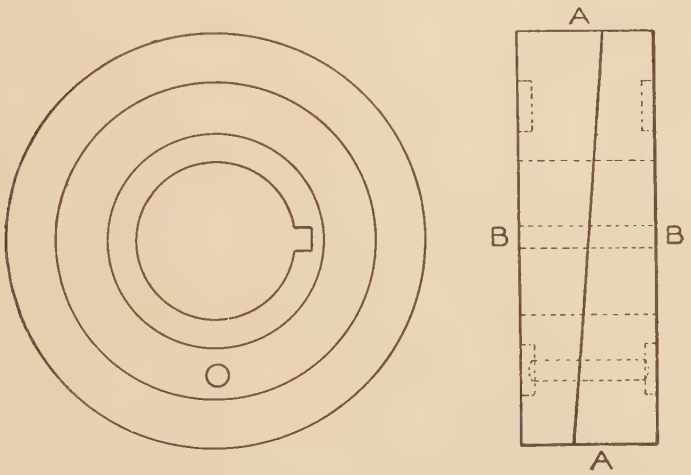

Fig. 186. Milling Cutter for Slots.

An excellent form of milling cutter to be used for milling slots or similar work may be made as shown in Fig. 186. This form is less expensive to make than one having interlocking teeth and answers the purpose as well. It is necessary to make an eccentric mandrel of the design shown in Fig. 187, having the eccentric centers on opposite

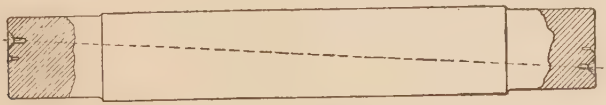

Fig. 187. Eccentric Mandrel for Slot Cutter.

sides of the regular centers as shown. The two pieces which make the cutter should be cut from the bar long enough to finish the thickness of the heaviest part *A A*, Fig. 186. The hole is made $\frac{1}{16}$ inch smaller tha finish size, the outside surface turned off, and the pieces annealed.

After annealing, the hole may be made the desired size for grinding. One of the pieces may then be placed on the eccentric mandrel, forcing it on until the side that is to be beveled is exactly in the center of the mandrel. The side *B* may be machined with the mandrel running on the regular centers, while the beveled side must be machined with the mandrel running on the eccentric centers. When

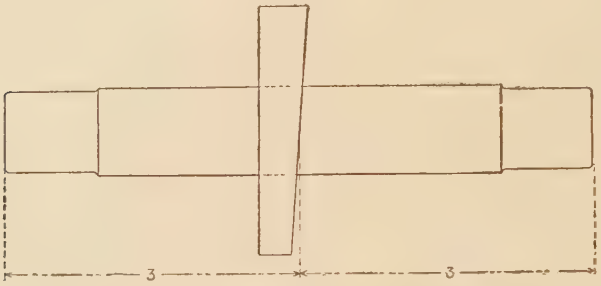

Fig. 188. Location of Cutter on Eccentric Mandrel.

the arbor is running on these centers, a distance half-way between the two ends runs true; it is at this point that the side of the blank to receive the bevel should be located, as shown in Fig. 188, provided the eccentric centers are of an equal depth. After machining the two parts of the cutter to shape, they should be so placed on a stud that the two beveled sides will be next each other as shown in Fig. 186, and the thinnest part of one next to the thickest part of the other. The pin-hole may now be drilled and reamed for a $\frac{3}{16}$-inch pin which should be inserted. The blank is next placed in the vise on the shaper or planer, and the spline slot cut as shown. It is now ready to be milled. After the cutter is hardened, the beveled sides may be ground true, the halves put together, the hole ground to size, and the cutter ground to thickness, after which the teeth may be ground for clearance. If it is found necessary to increase the width of the slot, it may be done by shimming between the two parts of the cutter with paper or thin sheet metal; the design of the cutter allows this to be done without leaving any fin in the slot.

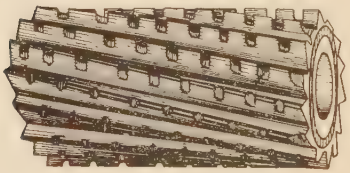

Fig. 189. Spiral Cutter with Nicked Teeth.

Nicked Teeth. Spiral cutters with nicked teeth, Fig. 189, are especially adapted for heavy milling. As the chip is broken up, a much heavier cut can be taken than would be possible were an ordinary cutter used. The nicking may be done as follows: An engine lathe may be geared to cut a thread of the required pitch—two threads to the inch will be found satisfactory—and with a round-nose tool $\frac{1}{8}$ inch wide, cut a thread of sufficient depth that it may not grind out

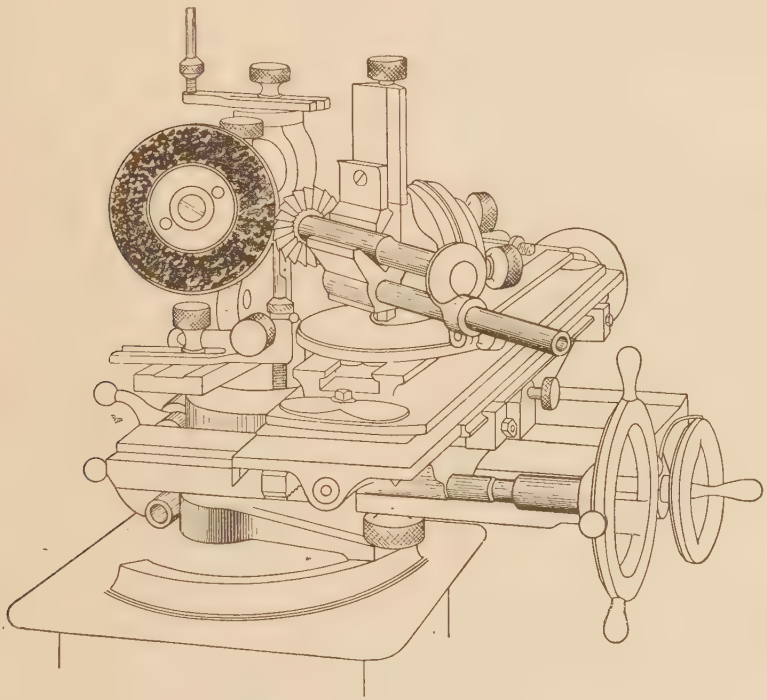

Fig. 190. Grinding Angular Cutter.

before the teeth will become too shallow to allow further grinding. This thread should be cut before milling the spaces to form the teeth.

Angular Cutters. When making angular cutters, the same general instructions given for making solid straight cutters should be followed, except that the desired angle should be given.

When milling the spaces which form the teeth, the index head is set at an angle that will cut the edge of the tooth of an equal

width its entire length. After removing the burs, the cutter may be hardened and tempered. The hole should be ground to size and the sides ground true with the hole. It should then be placed on a mandrel or stud, and the teeth ground for clearance. Fig. 190 shows the method used in grinding the teeth of a mill of this form.

Milling Cutters with Inserted Teeth. When milling cutters exceed 6 or 8 inches in diameter, it is generally cheaper to make the body of cast iron or machine steel, and insert in the periphery, teeth made of tool steel or high-speed steel. There is a variety of methods for holding the teeth in place. If the cutter is narrow, or is to be used as a side milling cutter, the grooves to receive the teeth may be cut

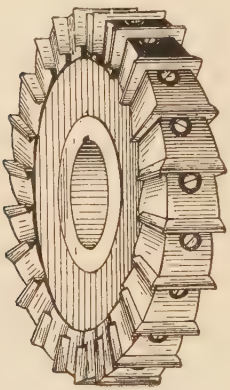

Fig. 191. Inserted Tooth Straight Cutter.

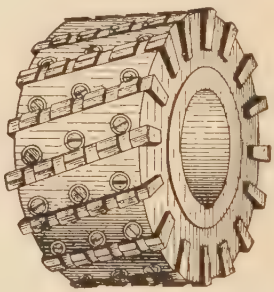

Fig. 192. Inserted Tooth Spiral Cutter.

straight (parallel to the cutter axis) as shown in Fig. 191. If the cutter face is over one inch long, the slots to receive the teeth should be cut in such a manner that spiral teeth may be used, as shown in Fig. 192.

While it is a comparatively easy matter to cut the slots spirally, it is difficult to make the teeth of a shape that will fit the spiral slots, without the aid of special tools. Consequently, the slots are generally milled at an angle to the cutter axis, having the side of slot that corresponds to the face of the tooth equidistant from a radial line at each end of the cut. The face of the slot at one end would be *ahead of the center*, while at the opposite end it would be *behind the center*; this gives what are termed *front rake* and *negative rake*, respectively.

The slots should be cut somewhat wider than would be necessary were the teeth to be made of spiral form. After turning to size, the faces of the teeth may be milled spirally to make them radial.

If the mills are intended for heavy work, the teeth may be nicked as already described. The coarse-pitch thread should be cut before the teeth are milled spirally.

After hardening, the teeth may be put in place and fastened, when they are ready for grinding. The emery wheel for grinding milling-machine cutter teeth should be of the proper grade as to hardness and coarseness; if the wheel is very *hard* or *fine*, it will be likely to draw the temper at the cutting edges of the teeth; the emery should not be coarser than No. 60, nor finer than No. 90.

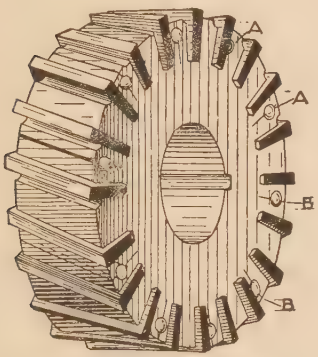

Fig. 193. Pratt and Whitney Cutter.

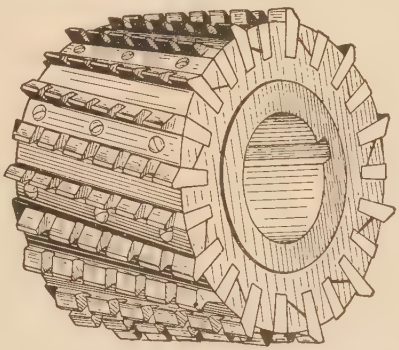

Fig. 194. Method of Fastening Teeth Used by Morse Twist Drill Co.

If the face of the wheel is glazed, remove the glaze with a piece of emery wheel somewhat harder than the wheel in use; this not only removes the glaze, but makes the surface of the wheel more open and less likely to glaze. The emery wheel should run true; its face should not exceed $\frac{1}{4}$ inch in width. Generally speaking, the softer the emery wheel, the faster it should run, but the peripheral speed should not exceed 5,000 feet per minute.

Fastening. There are several methods for fastening the teeth in this form of cutter, any one of which gives satisfaction if the work is well done. The method illustrated in Fig. 193 is in use in the works of the Pratt and Whitney Co., of Hartford, Conn. In this design, between every second pair of teeth, a hole is drilled and reamed taper to receive the taper pin *A A*, after which the slots *B B* are cut

with a thin cutter. After the cutters are in place, the taper pins *A A* are driven into the holes, thus locking the cutters. To remove the cutters, the pins are driven out.

A method used of fastening the cutters used by the Morse Twist Drill & Machine Co., of New Bedford, Mass., is shown in Fig. 194.

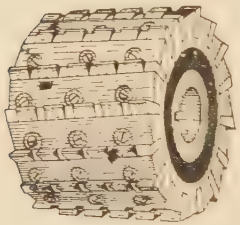

Fig. 195. Brown and Sharpe Cutter.

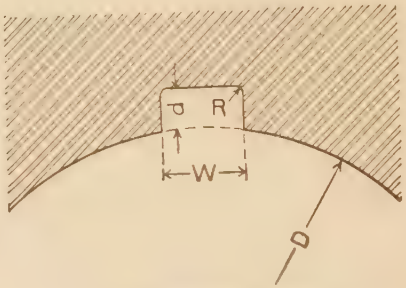

Fig. 196. Standard Keyway.

In this case the stock between every second pair of teeth is milled away, not so deep, however, as the slots for the cutters. Wedge-shaped pieces of steel are fitted between the teeth as shown. When these are drawn to place by means of fillister-headed screws, they bind the cutters very securely. If the wedge-shaped binding blocks

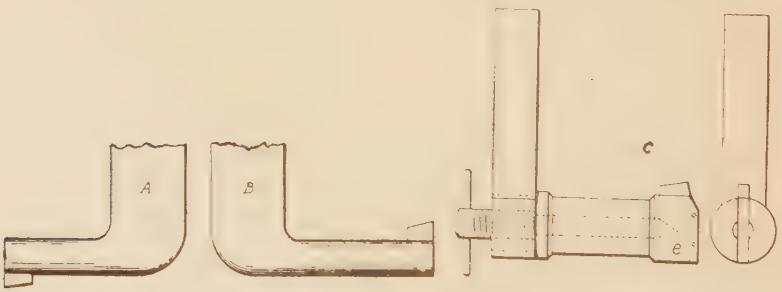

Fig. 197. Forms of Keyway Cutters for Planer or Shaper.

touch the bottoms of the slots, they will not hold the cutters securely in place.

The method shown in Fig. 195 is used by the Brown & Sharpe Mfg. Co., of Providence, R. I. The teeth are held in place by taper bushings and screws as shown.

Standard Keyways. To prevent milling-machine cutters turning

on the arbor when cutting, it is necessary (especially when taking heavy cuts) to have keyways cut as shown in Fig. 196 and Table IX.

The arbor, of course, must have a similar slot to receive the key. It will be noticed that the dimension *D* refers to the diameter of the *hole* in the cutter, and not to the diameter of the *cutter*. A key-seating machine equipped with the proper tools, furnishes a very satisfactory method of cutting keyways in milling-machine cutters; however, all shops are not provided with such a machine. The form of tool shown at *A*, Fig. 197, is extensively used for such purposes on the planer, or shaper, and works nicely if everything about the machine is in good condition. If, however, there is any looseness in any of the parts, or any backlash in the vertical feed-screw, the form shown at *B* will be found more satisfactory, as it is fed *up* in the operation of cutting, and so the backlash would not prove a source of annoyance. The writer has found this form of tool to work nicely on all interior cutting on the shaper and planer. It is necessary to clamp the tool-head so that it cannot rise on the return motion of the planer.

TABLE IX

Standard Keyways for Cutters

Diameter (*D*)	Width (*W*)	Depth (*d*)	Radius (*R*)
3/8 to 9/16 in.	3/32 in.	3/64 in.	.020 in.
5/8 to 7/8 "	1/8 "	1/16 "	.030 "
15/16 to 1 1/8 "	5/32 "	5/64 "	.035 "
1 3/16 to 1 3/8 "	3/16 "	3/32 "	.040 "
1 7/16 to 1 3/4 "	1/4 "	1/8 "	.050 "
1 13/16 to 2 "	5/16 "	5/32 "	.060 "
2 1/16 to 2 1/2 "	3/8 "	3/16 "	..060 "
2 9/16 to 3 "	7/16 "	3/16 "	.060 "

As all stock is not perfectly homogeneous, tools of the description shown will not always cut an absolutely straight slot. For most purposes the amount of variation need not be considered; but when an absolutely straight cut is necessary, the form of tool shown at *C* is used The portion marked *e* is made one or two one-thousandths of an inch smaller than the hole through which it is to pass. The cutter is set in a slot which passes through the tool as shown, and is fed into the work by means of the pointed feed-screw shown.

Formed Cutters. As used by the Brown & Sharpe Mfg. Co., the term *formed cutter* applies to the cutters with teeth so relieved that they can be sharpened by grinding without changing their form. However, the term can be applied to any cutter cutting a form regardless of the manner in which the teeth may be relieved. Fig. 198 represents a formed cutter. Formed cutters are used in many shops where work of irregular shape is milled in large quantities, as in sewing-machine, gun, bicycle, and automobile shops.

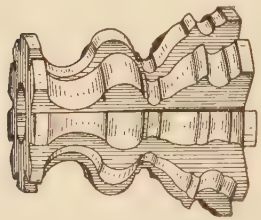

Fig. 198. Formed Cutter.

If many formed mills are to be made, it is advisable to procure or make a machine specially designed for relieving—backing off—the

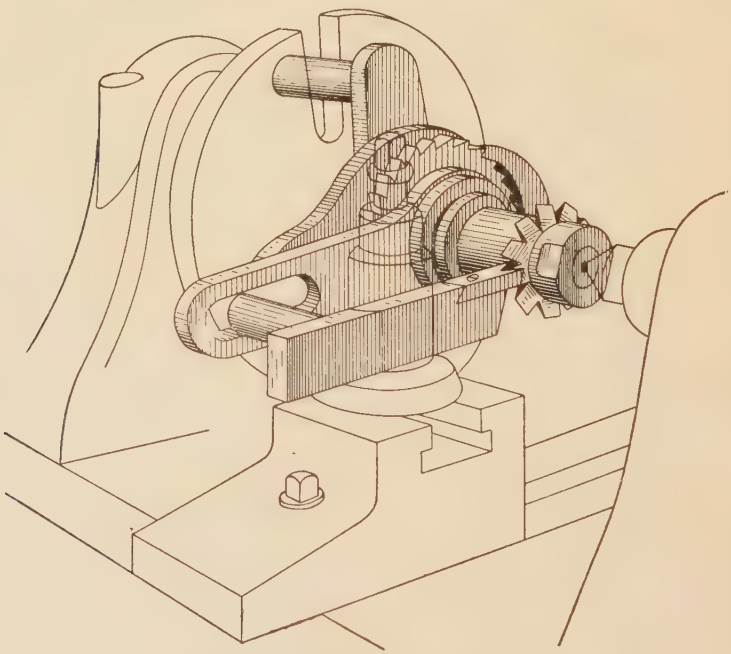

Fig. 199. Balzar Backing-off Attachment.

teeth. As such machines are heavy and rigid, large cutters may be relieved and a smooth cut obtained, which is not possible with a light machine.

While this style of cutter can be made to better advantage in a shop equipped with machinery designed especially for this class of work, an ordinary engine lathe can be converted to a *backing-off lathe* for relieving or backing-off the cutters. Or, a comparatively inexpensive fixture (known as the *Balzar backing-off device*) may be used. However, a simple arrangement consists of an eccentric arbor operated by a hand-lever. Or, a stud may be screwed in the face-plate of a lathe and the cutter placed on this stud in a position that allows the teeth to be given the necessary amount of clearance. When backing-off the teeth of cutters whose faces do not exceed one inch in width, the Balzar backing-off fixture shown in Fig. 199 can be used to advantage. This device is held between the centers of a lathe in the ordinary manner, the backing-off being such that the cutter can be ground without alteration of shape. The tool is so constructed that it is only necessary to place the cutter upon the arbor in the ordinary way. Place the arbor on the lathe centers as shown, start the lathe, and feed the forming tool in by the cross-feed screw in order to take the desired cut, in the same manner as in plain turning. The ratchet connected with the arbor and actuated by the pawl, contains ordinarily 36 teeth, and the stroke can be set to back-off a cutter with 9, 12, 18, or 36 teeth.

Fig. 200. Arbor for Backing-off.

Backing-Off by an Eccentric Arbor. An arbor may be made having a pair of centers located to give the cutter tooth the required amount of clearance; such an arbor is shown in Fig. 200. The eccentric centers are shown at the sectional portions at the ends. The amount of eccentricity depends somewhat on the size of the cutter to be backed-off; but for cutters not exceeding 4 inches diameter, from $\frac{3}{16}$ to $\frac{1}{4}$ inch will give excellent results.

The screw at the end of the arbor should be of a fine pitch, about 12 threads per inch for arbors one inch in diameter. The object in cutting a fine pitch thread is that the cutter being backed-off may be held more securely with the same amount of power exerted in tighten-

ing the nut; again, the depth of the thread is not so great as for a thread of coarser pitch, and, as a consequence, the plane portion at the end of the arbor (which is made the size of the bottom of the thread) may be left large enough to get in a center hole of good size having $\frac{1}{4}$-inch eccentricity.

The spline should be cut at least $\frac{1}{8}$ inch wide and about $\frac{1}{8}$ inch

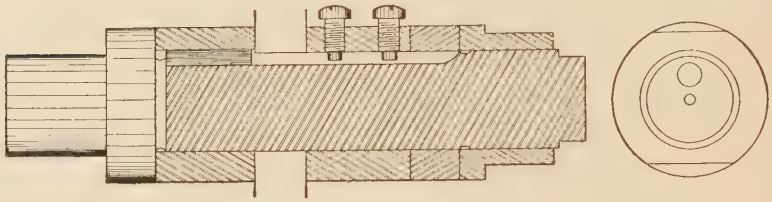

Fig. 201. Eccentric Arbor for Backing-off Cutter.

deep; the walls of the cut should be parallel in order that the screws shown in Fig. 201 as passing through the collar and entering the slot in the arbor, may have a good bearing. These screws are to keep the collar from turning when the necessary power is applied to the nut for fastening the cutter in place. The collar on the opposite side of the cutter has a spline cut the same width as cut in the arbor, and

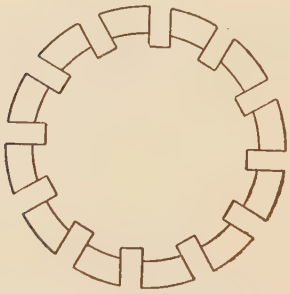

Fig. 202. Cutter Blank with Grooves.

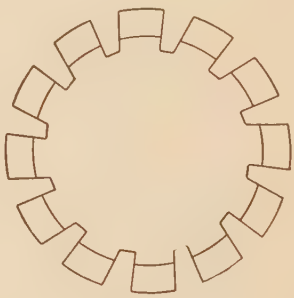

Fig. 203. Grooves Made by Angular Cutter.

is held in position by a spline, as shown. The cutter cannot be held by a spline, as it is necessary to move it each time a tooth is brought into position for backing-off.

When machining the cutter blank, it is given the desired shape by means of a forming tool. If the shapes vary much in size, the shape may be roughed out before using the forming tool. After it

has been machined to the desired size and shape, it may be placed between the centers of the milling machine, and a number of grooves cut the entire length of the cutter. The number of grooves must correspond to the number of teeth the mill is to have; these grooves cannot be cut to finish width until after the teeth are backed-off, because the forming tool cuts a trifle deeper at the point of contact, making it necessary to mill a small amount from the face of the tooth after backing-off. The grooves are sometimes cut with a thin milling cutter, or a metal slitting saw $\frac{1}{8}$ inch thick. When a groove of this description is cut, the cutter has the appearance shown in Fig. 202. Cutting a groove of this form makes more work for the operator than when cut as shown in Fig. 203, in which the distance across the tops of

Fig. 204. Angular Cutter.

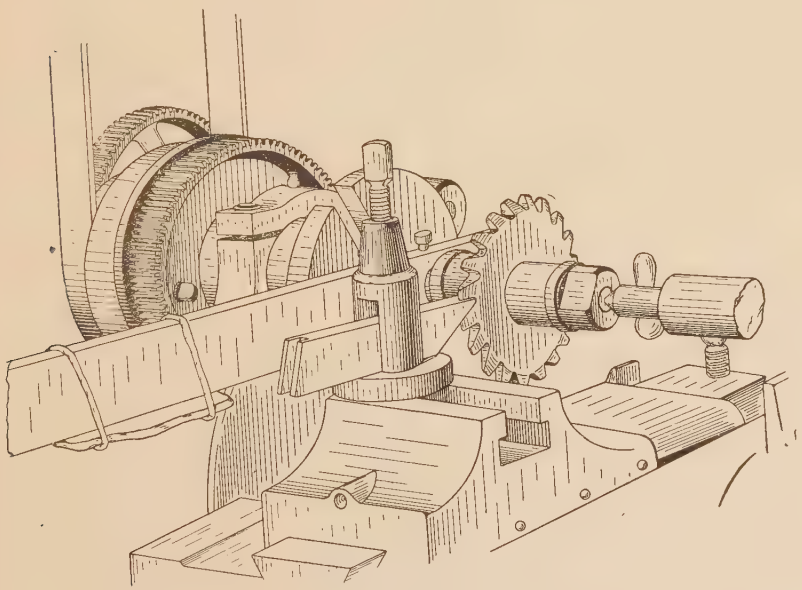

Fig. 205. Ready to Back-off Cutter Teeth in Lathe.

the teeth is decreased by using an angular cutter of the shape shown in Fig. 204. After cutting the grooves, the cutter may be placed on

the eccentric arbor, which is held between the centers of the lathe in the ordinary manner. A forming tool that will produce the desired shape of tooth is placed in the tool-post; the top face of the tool must be set at the exact height of the center of the lathe in order to produce the proper shape. Fig. 205 shows an eccentric arbor in a lathe in position to back-off the teeth in a formed mill. The arbor is operated by means of the lever. The arbor is entirely independent of the spindle in its action, the eccentric centers being placed on the centers of the

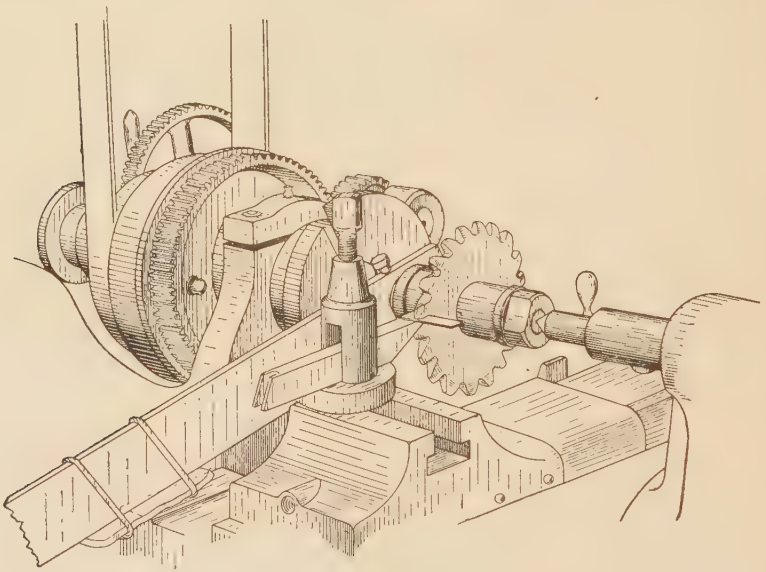

Fig. 206. Locating Cutter Tooth for Backing-off.

lathe, and the necessary motion given by means of the lever which strikes the carriage at the end of the stroke. In order to avoid bruising the lathe, a strip of leather is attached to the lever, as shown.

To set the cutter tooth in the proper location before backing-off, a piece of thin sheet metal is placed on the top face of the tool, as shown in Fig. 206. The lever is brought down upon the carriage, the tooth of the cutter is brought down upon the sheet metal, and the nut is tightened. The tooth to be backed-off is the one below that set to the thickness of the strip above the tool. The object in raising the tooth a given distance above the face is to prevent striking the tool at the end of the stroke. Again the teeth are

set alike. This operation must be repeated for the setting of each tooth before backing-off. The forming tool is fed by means of the cross-feed screw; a tooth is backed-off nearly the desired amount, leaving a little for a finish cut; the tool is withdrawn, the nut loosened, and the cutter turned on the arbor to bring the next tooth in position to be backed-off. This operation may be repeated until all the teeth are backed-off alike. The amount of backing-off must be determined by the cross-feed stop or by a graduated dial on the cross-feed screw. After the roughing cut has been taken on all the teeth, the forming tool may be sharpened by grinding or by oil-stoning, and the finish cut taken on the teeth. Another method of backing-off cutter teeth is shown in Fig. 207. A stud is screwed in the face-plate of a lathe

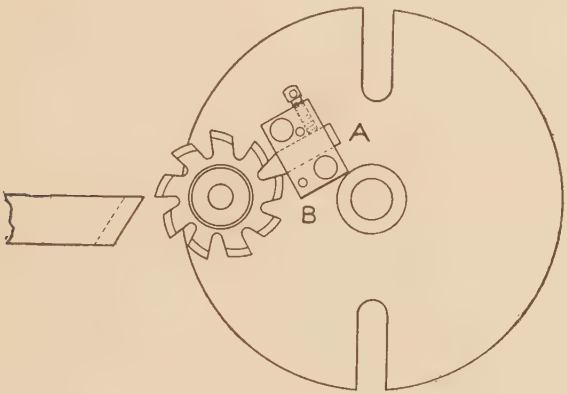

Fig. 207. To Back-off Cutter on Face-plate.

near the outer edge, as shown. The cutter, which must be a fit on the stud, is clamped by means of the nut shown. The finger *A* is movable in the slot in the stationary block *B*, which is so located on the face-plate as to bring the tooth to be backed-off into its proper location, and keep it from turning during the operation. The forming tool is fed in gradually until the tooth is formed. The finger is then disengaged from the space in the cutter which is revolved by means of the set screw until the next is in position. Each tooth is machined separately; that is, the forming tool is fed in the required distance for each tooth when it is in position. The cutter is turned until the next tooth is in position, and the process repeated until each tooth has been backed-off.

In backing-off cutters in this device, it is necessary to cut the notches (spaces between the teeth) somewhat wider than the teeth.

When backing-off the teeth for clearance by any of the means described, it is first necessary to form the blank, then gash it or cut the notches as described; then back-off the teeth. After backing-off, it is necessary to mill the face of the tooth back $\frac{1}{32}$ inch or so, to cut away the *jump* (as it is termed) caused by the forming tool drawing in a trifle when it first strikes the edge of the tooth.

Threaded Holes. It is often necessary to make milling cutters with threaded holes. This happens in the case of small angular cutters, and many styles of cutters for use on profiling (edge milling) machines.

The same general instructions for making the other forms of cutters apply to those with threaded holes, except that, instead of reaming the hole to a given size, the thread is cut with a tap of the proper size and pitch, or it is chased in the lathe. After threading, the cutter should be screwed onto a threaded arbor. Fig. 208 shows an

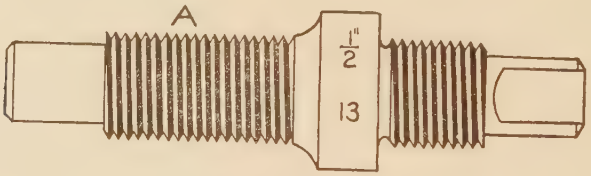

Fig. 208. Threaded Arbor.

arbor of this description. The end *A* is threaded slightly tapering, for short cutters, about .002 inch in one inch of length. On the taper end of the arbor, a thread should be cut of a size that will not allow the cutter to screw on the arbor quite the entire length; that is, the cutter should overhang the threaded portion of the arbor a trifle (say one thread); this allows the outer end to be squared up without mutilating the threads on the arbor. The reason for using the taper end of the arbor when squaring the first end of the cutter, is that the shoulder is true with the thread in the cutter. After squaring this shoulder, the cutter blank may be removed and placed on the opposite end of the arbor with the side that has been squared against the shoulder of the arbor. This method of machining pieces of work having a threaded hole, where it is desirable that the outer surfaces

be true with the hole, is applicable to all classes of work. The cutter may be machined to length and shape on the straight end of the arbor.

Fly Cutters. The simplest form of milling-machine cutter is known as a *fly cutter*. It has only one cutting edge, but is particularly valuable when making but one or two pieces of a kind for experimental work, and when making and duplicating screw-machine and similar tools of irregular shape.

As these cutters have but one cutting edge, they produce work very accurate as to shape, but cut very slowly and do not last as long as those having more teeth. However, they are used on special work, on account of the small cost of making. It is necessary to hold the cutters in a *fly-cutter arbor*, which is shown in Fig. 209.

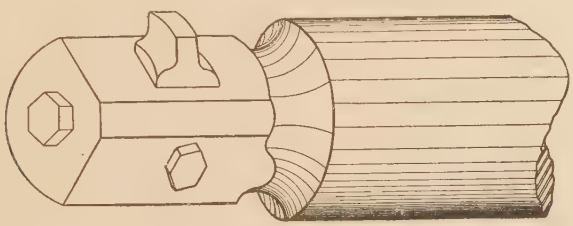

Fig. 209. Fly-Cutter Arbor.

The cutter to be used in a fly-cutter arbor may be filed to a templet, giving the necessary amount of clearance in order that the back edge, or *heel*, may not drag. If it is desirable to make the impression in the fly cutter with a milling cutter of the regular form, the piece of square steel from which the cutter is to be made may be held in the milling-machine vise, and the shape cut with the milling cutter. The desired amount of clearance may be given by holding the piece in the vise at an angle of a few degrees.

To make a fly cutter from a forming tool, the piece of steel may be held in the fly-cutter arbor in such a position that the face is somewhat back of a radial line, as shown in Fig. 210. After hardening, the cutter may be set so that the cutting edge will be radial and the clearance will be as shown in Fig. 211.

Another method of getting the clearance for the cutter is to place the top of the cutter blank as near the arbor as possible, and then cut the desired shape. If the cutter is set in the arbor so that it projects

from the surface, it will have the necessary clearance as shown in Fig. 212. *A* represents the position of the blank while being cut, and *B* the cutter in position for cutting; the dotted line showing the circle through which the cutting edge travels, the amount of clearance is apparent.

End Mills. This form of milling-machine cutter, Fig. 213, is familiarly known as a *shank mill.* The term is used on account of

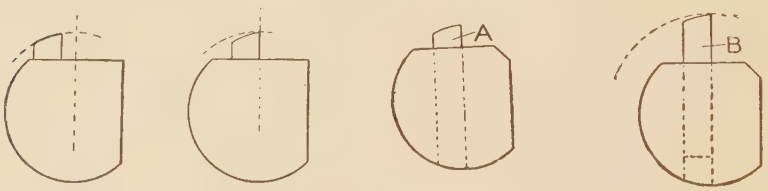

Fig. 210. Fig. 211. Fig. 212.

Two Methods of Providing Clearance for a Fly-Cutter.

the shank *B*, which in small milling cutters fits into a collet. This collet in turn fits the hole in the spindle of the milling machine. The collet referred to is used to save stock in making the cutters, as otherwise it would be necessary to use steel large enough to make a shank the size of the hole in the spindle of the milling machine.

The cutter shown in Fig. 213 is what is termed a *left-hand* mill; if the teeth run in the opposite direction, it is called a *right-hand* mill.

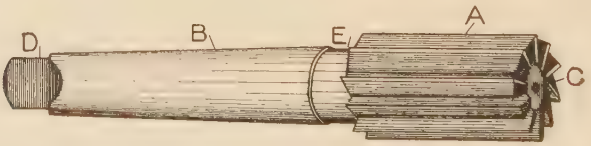

Fig. 213. Left-Hand End Mill.

In making a shank (or end) mill of the form shown in Fig. 213, stock should be selected enough larger than the cutting end *A* to allow of turning off the decarbonized surface of the steel. After facing the ends to length, and turning the roughing chip, the end *A* may be run in the steady rest of the lathe, and the center cut away—or recessed—as shown at *C*. The blank should be recentered and countersunk, to furnish a center to use in turning the mill to size and shape. The object in cutting the center out as shown, is to furnish

a cavity for the angular cutter used in cutting the teeth on the end of the mill. Without this, it would be impossible to grind satisfactorily.

After recentering the end C, the tenon D may be turned to size and milled to thickness, which should be a trifle ($\frac{1}{32}$ inch) less than the width of the center key slot in the collet. The taper at B should be turned enough larger than finish size to allow for grinding after the

Fig. 214. Weak Teeth.

Fig. 215. Well-Formed Teeth.

Fig. 216. Strong Teeth.

Fig. 217. Cutting Strong Teeth.

milling cutter is hardened. The cutter end A should be turned .010 inch larger than the required diameter. The portion E should be turned $\frac{1}{32}$ inch smaller than the large end of B, or to dimensions if any are given on the drawings.

In order to insure teeth strong enough to resist the strain of cutting, an angular mill should be selected that will give the required shape. In Fig. 214 is shown a form of cutter tooth too weak for

Fig. 218. Spiral End Mill.

actual service; this tooth is the result of using an angular cutter with a cutting face forming an angle that is too acute with the side. Fig. 215 shows a cutter whose teeth are strong, yet deep enough to be practical; these teeth were cut with an angular mill of less angle. Fig. 216 represents a cutter whose teeth were cut with the same cutter used for Fig. 214. The teeth were cut to the required depth first, this of course leaving them too thick at the cutting edges, as shown in Fig. 217. After cutting the teeth as shown at A, Fig. 217, the index head was turned sufficiently to cut the teeth as shown at A, Fig. 216.

After cutting the teeth around the circumference of the mill, it should be placed in the collet, and the collet put in the spindle hole in the spiral head in order to cut the teeth on the end.

When cutting the teeth on the end of the mill, the spiral head is turned until the cutter is in a horizontal position. The angular cutter used should not have a very acute angle, or the teeth will be weak. An 80° angular milling cutter will be satisfactory for most work.

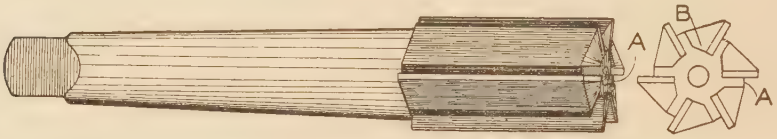

Fig. 219. End Mill with Center Cut.

Spiral End Mills. It is sometimes advisable to cut the teeth of end mills spirally, as shown in Fig. 218. As there is no support at the outer end of this form of mill, it will be necessary to cut the teeth of a spiral that will have a tendency to force the mill into the collet rather than draw it out. Fig. 218 represents a left-hand end mill cut with a right-hand spiral.

End Mills with Center Cut. This form of end mill is useful when it is necessary to cut into the work with the end of the mill,

Fig. 220. Projection Left by End Mill.

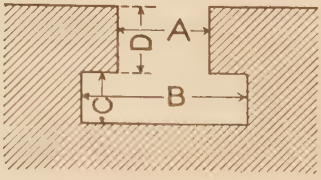

Fig. 221. T-Slot.

and then move along, as in dies, cams, and grooves. The teeth, being sharp on the outside, cut a path from the point of entrance. The coarser teeth allow a heavier cut, especially in cast iron. Fig. 219 shows two views of an end mill with center cut.

After cutting the teeth on the end with an angular cutter, a thin, straight-faced cutter of small diameter should be run through, close

to the face of the cutter tooth, making a cut as shown at *A*; this cut should be of sufficient depth to permit of backing-off the inner edge of the tool, as shown at *B*. This clearance allows the mill to cut away the slight projection left in the center of the mill when it is fed into a piece of work. Such a projection is shown at *A* in Fig. 220.

T-Slot Cutters. In cutting T-slots in various parts of machines, such as milling-machine carriages, etc., it is necessary to use a form

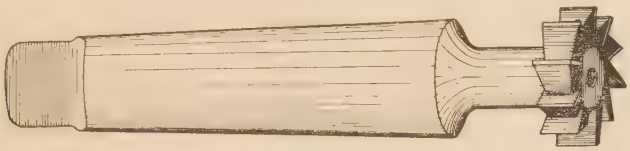

Fig. 222. T-Slot Cutter.

of shank mill known as a *T-slot cutter*. Fig. 221 shows the ordinary form of T-slot; while Fig. 222 shows the cutter. A portion of the stock below the teeth is cut away as shown at *A A* in the sectional view, Fig. 223. This is necessary in order to back-off the teeth on the sides of the cutter for clearance, and to do away as far as possible with unnecessary friction when the cutter is working.

T-slot cutters are usually made $\frac{1}{32}$ inch larger in diameter than the size designated on the cutting portion, to allow for sharpening; that is, a mill intended for cutting a slot $\frac{1}{2}$ inch wide is made $\frac{1}{2} + \frac{1}{32}$ (or $\frac{17}{32}$) inch diameter, unless intended for cutting a slot to given dimensions.

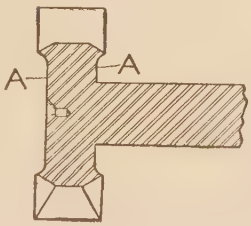

Fig. 223. Section of Cutter.

It is advisable to harden mills of this description the entire length of the neck, especially if the neck is of small diameter; otherwise they will be very likely to spring when in use. After hardening, the neck should be drawn to a blue color, while the cutting part should be drawn to a straw color.

When grinding end mills, the shank in all cases should be ground first to fit the collet or holder, allowing it to enter *far enough* to key out readily, yet not enough to allow the shoulder above the tenon to strike the shoulder in the collet.

After grinding the teeth for clearance on the diameter, the teeth on the end should be ground. Most universal and cutter grinders are provided with a fixture for holding the mill by the shank while grinding these teeth; such a fixture is shown in Fig. 224.

Face Milling Cutters. This form of cutter is used in milling surfaces too large to be cut with the ordinary form of milling cutter held on an arbor passing over the work. As the full diameter of the

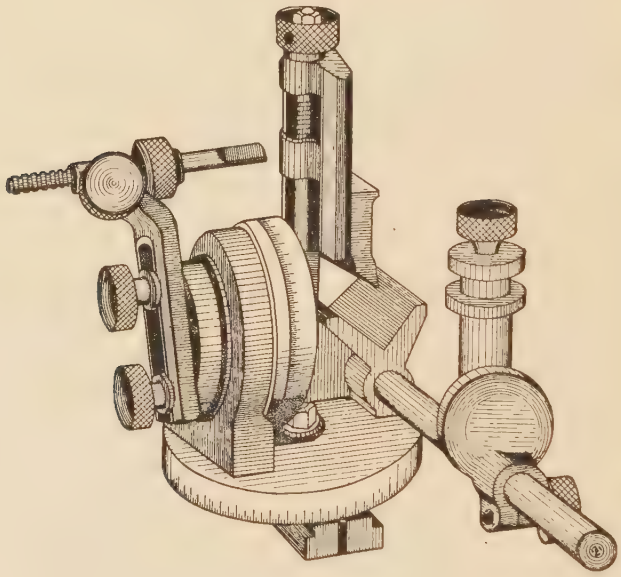

Fig. 224. Cutter Grinder Fixture for Mill.

face of the cutter may be used, it may have less than one-half the size that would be necessary for a side milling cutter. A side milling cutter must be double the diameter of the surface to be cut, plus the diameter of the collar on the arbor. For instance, if a surface as *A*, Fig. 225, were to be milled, it would be necessary to use a cutter somewhat larger in diameter than twice the height of the surface plus the diameter of collar *B*. Whereas if a *face* milling cutter of the form shown in Fig. 226 were used, the diameter need not be much greater than the height of the face of the piece of work being milled.

Generally speaking, cutters of this description are necessarily of a diameter that makes it advisable to use inserted teeth as shown in Fig. 226. The body may be made of cast iron, having a taper hole and keyway, and held in place on the arbor by a screw.

The teeth may be made of tool steel and hardened, or of high-speed steel, if the cutter is to be subjected to rough usage. In either case, they may be fitted to the slots by grinding on a surface grinder,

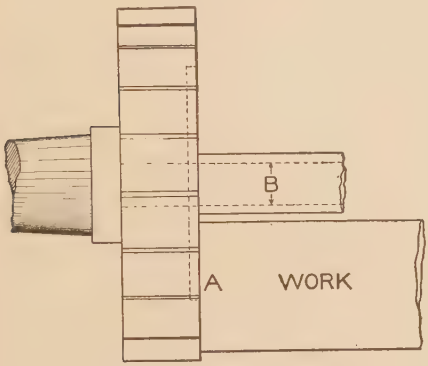

Fig. 225. Side Milling Cutter on End Work.

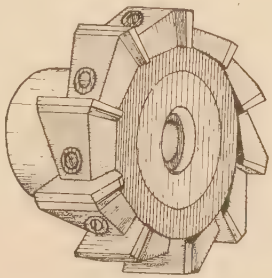

Fig. 226. Face Milling Cutter.

and held in place by taper bushings and screws, as explained under "Milling Cutters with Inserted Teeth." The construction of the body may be readily understood from the sectional view given in Fig. 227. The letters *A*, *B*, and *C* represent the diameter of cutter, width of face, and number of taper of the hole, respectively; while *D* represents the keyway.

Table X gives the dimensions of face milling cutters of different diameters.

TABLE X

Face Milling Cutters

Diameter of Cutter	Width of Face	No. of Taper of Hole
5½ in.	2 in.	No. 10 Browne & Sharpe Taper
6½ "	2 "	" 12 " " " "
7½ "	2 "	" 12 " " " "
8½ "	2⅜ "	" 12 " " " "
9½ "	2⅜ "	" 12 " " " "

After boring and reaming the taper hole, the body of the cutter may be placed on a taper mandrel fitting the hole, and the ends and circumference finished to size. It should then be placed in the vise on the shaper or planer at the proper angle, and the spline slot cut to an equal depth at each end of the taper hole. After removing the burs, it should be placed between the centers on the milling machine, and the slots cut for the teeth.

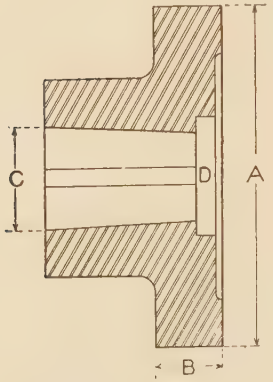

Fig. 227. Body of Face Mill.

When the teeth are firmly secured in their proper places, they may be ground for clearance. The same general instructions given for grinding other forms of milling machines apply to this form.

Arbors for Face Milling Cutters. In Fig. 228 is shown an arbor to be used in connection with face milling cutters. The shank *A* fits the hole in the spindle of the milling machine. *B* is the body which fits the taper hole in the cutter; this portion of the arbor has a spline which fits a spline slot in the cutter. A screw *C* enters the body of the arbor, and is used in holding the cutter on the arbor. *D* is a nut used to force the cutter off the arbor when it is necessary.

Stock used in making an arbor for a face milling cutter should be strong and stiff, and on this account tool steel is generally used.

Fig. 228. Arbor for Face Milling Cutter.

After squaring the ends and roughing out the circumference, one end should be run in the steady rest, and the screw-hole in the end drilled and tapped, after which it should be countersunk at the end to furnish a center for use in turning and finishing. If necessary to harden the end of the tenon, it should be done before finish-turning the arbor, to prevent springing when heating. After turning the

taper to fit the hole in the milling-machine spindle, and on the opposite end to fit the cutter, the thread may be cut for the nut *D*, Fig. 228, after which the arbor may be cut for the spline as already explained.

The result will be more satisfactory if the two tapers are left a trifle large until after cutting the spline cut and are then ground to fit. Although the spline is intended to fit snugly in the slot in the arbor, the fit should not require pressure enough to endanger the truth of the arbor when it is pressed to position.

MILLING-MACHINE FIXTURES

When producing work by milling operations, it is necessary to use good cutters; it is equally necessary to employ suitable means of holding the work. It is a waste of money to make costly cutters, and to purchase a heavy, strong machine, and then use a weak, poorly designed holding device.

When unsuitable holding fixtures are used, accurate work cannot be produced unless extremely slow feeds are employed; and even then, it is many times found impossible. In fact, the designing of fixtures to hold work in the milling machine calls for as great a display of ingenuity as the designing of any class of tools used in the shop.

Years ago, almost all pieces produced by the milling machine were purposely left large in order that they might be brought to exact size by filing. To-day most pieces are milled to finish size, thus doing away with the costly operation of filing. Now in order to produce work of the desired accuracy, cutters must be used that are of the right shape. Machines must be provided that are strong and rigid, and which may be easily operated. *Holdfasts* must be employed which will hold the work and insure its being presented to the cutter in such a manner that all pieces will be alike, in order that perfect interchangeability of parts may be assured. This is impossible with light fixtures, as they will spring, and not only will the sizes vary, but the surface of the work will be covered with chatter marks.

Not only must the fixture be rigid and strong, but the holding devices must be of a design that allows of rapid handling of the work. All bearing and locating surfaces and points must be accessible, to allow of ease in cleaning, as a collection of chips, or dirt, or at times,

the presence of even one chip, would change the location of the piece to an extent that would prove fatal to the work.

Most fixtures of this kind are made from cast iron; and as this is a cheap metal that is easily gotten to shape, it is possible to supply a sufficient amount to insure necessary rigidity. For fixtures that are to be used over and over, it is advisable, generally speaking, to supply seating and binding surfaces of hardened steel.

When designing fixtures, plan to have the strain incident to binding the work and cutting it with the cutters come against the strongest part, if possible. Fig. 229 shows several holding devices.

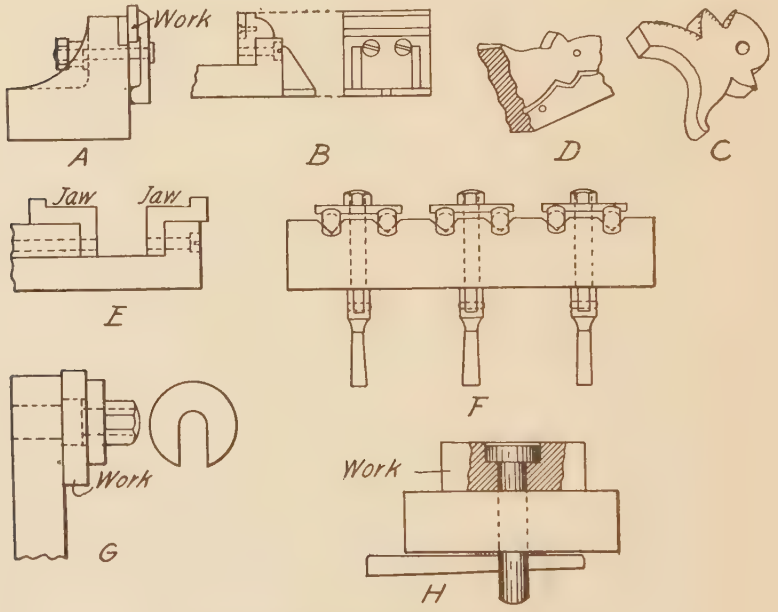

Fig. 229. Forms of Milling-Machine Holdfasts.

A is made in the form of an angle iron. The strain of binding and the cutter strain both come against the rigid part. If the fixture were reversed, the cutter strain would come against the strap, and it would be found impossible to produce work to gauge if heavy cuts or moderately coarse feeds were employed.

In the same figure, at *B*, is shown a portion of a *milling-machine vise*, the work being held between steel jaws. If the work were of a character that made it possible to use jaws extending but little above

the top of the vise, it would not be necessary to use heavy jaws; but in the illustration, the jaws extend quite a little above the top of the vise, and even heavy jaws would spring, or would draw away from the vise at the bottom, thus throwing the work out of true. To prevent this, they are made of the form shown, and bear on the top of the vise.

When pieces are milled, a bur is thrown out as shown at *C*. At times this bur will bear against the bearing surfaces of the fixtures, thus throwing the work out of true; and the burs will be pressed into the work, thus mutilating and spoiling it. Frequently these burs are removed by filing or grinding. At times this seems an unwarranted expense, as subsequent operations would cut them away at no expense. Under these conditions it is possible to cut into the bearing surface and remove enough stock to provide a place for the bur, as shown at *D*.

When it seems advisable to hold work in the vise, and the opening is not sufficient to take in the piece, the jaws may be made as shown at *E*.

When a *cam* will fasten the work to the fixture strongly enough, it proves a rapid method, and one that is often employed. At *F* is shown a fixture for holding bolts whose heads are to be straddle-milled as shown. One cam binds two bolts; and as three cams are provided, six bolts may be milled at a time. The fixture is so designed that the cam handles are at the front of the fixture rather than back of the cutters, as in this position the operator's hands would be in danger. The cutter pressure is against the solid part of the fixture, thus insuring rigidity.

At times cams do not prove satisfactory, and it is found necessary to use a *screw*. Screws are slow of operation, as it takes a long time to turn them back and forth sufficiently to bind or free the work. To facilitate matters, a slotted washer *G* is sometimes provided, and a screw which passes through a hole in the work is used. By this means it is necessary to turn the screw but part of a turn in order to allow of binding or removing the washer.

When it is necessary to locate the binding device on the under side of a fixture or in some inaccessible place, a *wedge-shaped key*, as shown at *H*, proves satisfactory. It holds the work solidly on to the seating surface, and is quickly and easily operated.

In Fig. 230, at *A*, is shown a piece of work whose ends are milled square. As the sides are machined on a slight taper to the axis of the piece, it was necessary to hold the work as shown at *B*, and use an end milling cutter.

In making fixtures of the kind under consideration, the designer should bear in mind that the simplest form which will insure desired

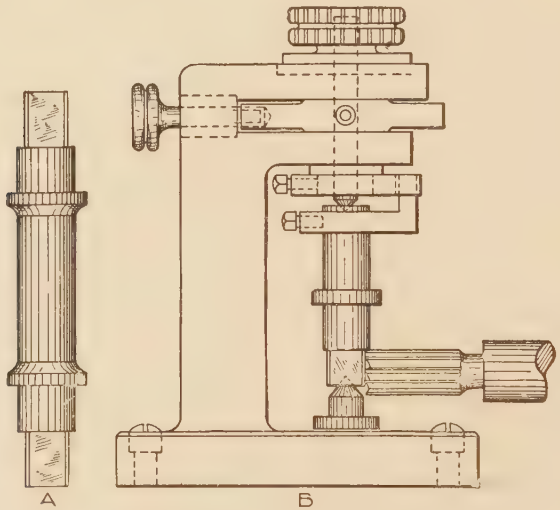

Fig. 230. Method of Holding Work for Milling the Ends Square with End Mill.

results at the minimum cost is the best. Always avoid complicated fixtures if a simple one will answer.

Fig. 231 shows a method of holding a spindle and milling a slot across the end. The piece of work is held in a fixture made in two parts. The cut is taken by feeding the knee vertically, by means of the automatic vertical feed. With a fixture of this description, the ends of long pieces can be milled as shown.

DRILL JIGS

A *drill jig* is a device for holding work so that one or more holes may be accurately drilled; the locations of the holes may be governed by hardened bushings (guides) through which the drills run.

The design of a jig depends entirely on the shape of the piece and the nature of the work to be done. Jigs should be so designed

that work may be placed in and taken out of them as quickly as possible. The fastening device should allow rapid manipulation, yet be capable of holding the work without danger of a change of location.

The construction of drill jigs calls for as great accuracy as any branch of the tool-maker's business; but no undue accuracy should be indulged in. If the location of a hole is near enough when within

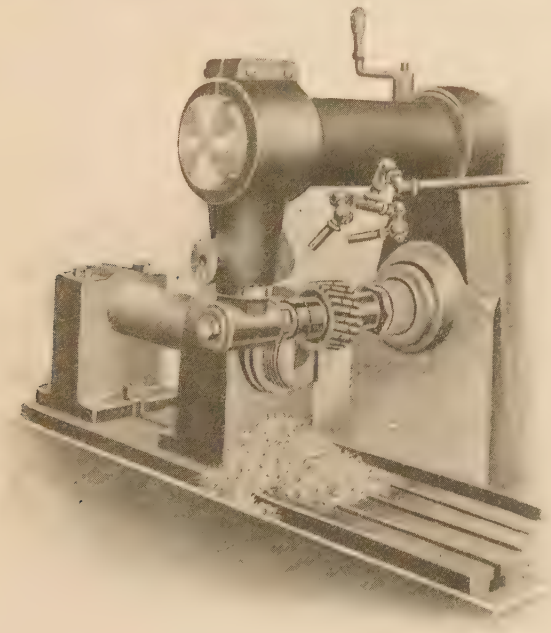

Fig. 231. Milling Slot across End of Spindle.

a limit of variation of $\frac{1}{16}$ inch, it is a waste of time to attempt to get it within .0005 inch. Yet if the work is of such character that it is necessary that the holes be within a limit of variation of .0001 inch or even closer, every effort should be made to locate the drill bushings as accurately as possible.

While the design of the jig and the character of the work to be drilled must necessarily determine the method of construction, a few general points may not be amiss. The amount of *finish* given the exposed surfaces of a jig must be determined by the custom or requirements of the individual shop. In many shops it is not considered

necessary nor advisable to finish the surfaces any more than to allow of their being wiped without the waste sticking to the jig.

Under other conditions the surfaces are *machined* as smooth as possible, and the surface finished by placing a piece of one-quarter or three-eighths inch wood dowel in the drill-press chuck, so that the dowel projects three-quarters of an inch or so from the chuck. The surface of metal is covered with a thin coating of oil and fine emery. The dowel, revolving at high speed, is brought down onto the surface, allowed to run for a few seconds, raised, and again lowered so that it cuts part way into the first circle. This is repeated until the whole

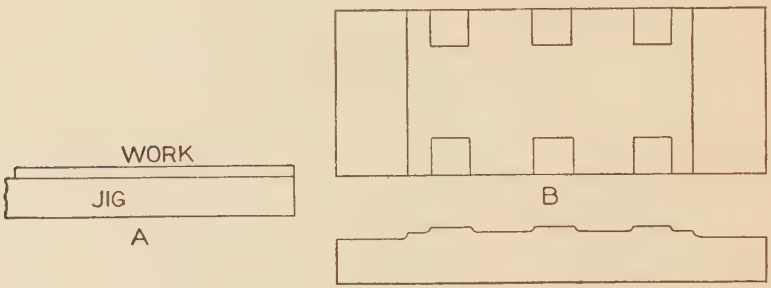

Fig. 232. Seating Surfaces for Drill Jigs.

surface is covered with the part circles. The effect is pleasing and the surface is not easily marked by light scratches that would show plainly on a highly finished piece of steel. It is an economical method of producing a fairly good finish.

A jig should be constructed so that it may be easily cleaned. Chips or dirt between the piece of work and the seating surface, or between the work and the stops, or locating points, throw the work out of true. As a result the holes will be at a wrong angle to the working surface, or they will be improperly located. Either condition would make the pieces unfit for use on most work; consequently bearing surfaces (wherever possible) should be cut away, leaving several small seating surfaces, rather than one large one. *A*, Fig. 232, shows a piece of work resting on its entire seating surface; while *B* shows a surface cut away to leave six bearing points. If the seating surface is to be cut away as described, the raised portions should be so located that the article cannot be sprung by the action of the cutting tools or from any pressure that may be applied by any fastening device;

otherwise the work will be thrown out of true as badly as though chips were lodged between the work and the seating.

It is advisable, whenever possible, to divide a long locating bearing into several short surfaces, thus decreasing the chance of holes becoming inaccurately located. When making jigs for pieces that are likely to have burs at any given point, it is well to cut a depression in the seating or locating surfaces for the bur to set in, thus preventing the work being incorrectly located.

Seating surfaces should be made smooth so that chips and dirt will not stick to them; but they should not be polished or finished, as this would necessitate unnecessary cost and might throw the surface out of true.

A jig must be handled by the workman, and a clumsy jig cannot be handled as readily as one designed so that the workman can use it to advantage.

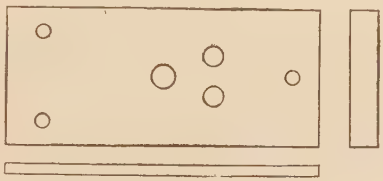

Fig. 233. Slab Jig.

Sharp corners should be avoided wherever possible, and all handles or similar devices should fit the hand. If not, the amount of work done will not be the maximum, as the operator cannot do as much work with a jig which tires the hand and wrist.

As already stated, the accuracy with which a jig should be constructed depends entirely on the nature of the work to be done; yet it should be borne in mind that any inaccuracy must of necessity be duplicated in the work.

Examples of Jigs. A few designs of jigs will now be considered, to show the general requirements and the methods of construction.

The *slab jig*, shown in Fig. 233, is the simplest form in use; it consists of a piece of flat stock of suitable thickness and of the same general outline as the piece of work to be drilled. The work may be clamped to the jig by means of U-clamps, or parallel-jaw clamps. If the jig is made of machine steel, the walls of the holes may be case-hardened by heating the jig red-hot and sprinkling powdered cyanide of potassium around the hole, reheating it in the fire, and plunging it in water; it should be worked back and forth in the bath so that the

water will circulate through the holes. While this form of jig answers very well where but a few pieces are to be drilled, it is not suitable for permanent equipment on account of the wear of the holes. To overcome this, the holes may be made sufficiently large to receive hardened bushings having holes the size of the drill to be used. Fig. 234 shows this construction.

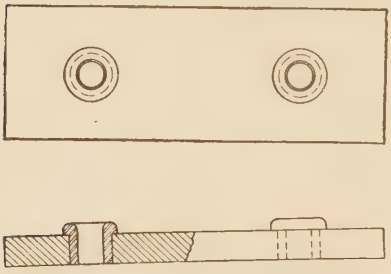

Fig. 234. Jig Provided with Bushings.

When holes are to be drilled at certain distances from one or more edges, it is necessary to have stops against which the work may rest. These stops may be pins, a shoulder, or a rib.

If the outline of the work has been finished by any process (as milling, punching, or profiling) that insures uniform lengths and widths, the locating points may be placed on all sides of the piece as shown in Fig. 235, in which pins are used as stops or locating points. It is necessary to flatten the pins on the sides that come in contact with the work, to prevent rapid wear.

When a jig is to be used constantly, it is advisable to have a shoulder or rib for the work to rest against, rather than pins, as the former will not wear so rapidly. Fig. 236 shows the same form of jig as Fig. 235, except that ribs are substituted for pins.

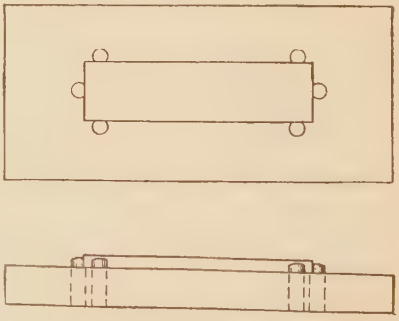

Fig. 235. Locating Pins on Jig.

When there is no surety that the dimensions of the different pieces are exactly alike, it is advisable to locate the pieces in the jig from certain portions. The work must be forced against the locating points by means of a screw, cam, or wedge. With a screw, the work may be forced to position and held there even when the dimensions of the piece vary considerably. The cam is operated much more quickly than the screw, and holds the work firmly when the size of the pieces varies but little. For certain purposes the wedge is an admirable holding device, but it is not generally used. Fig. 237 shows a jig in

which the work is located from one side and end; the work being forced against the stops by means of a screw. Fig. 238 represents the same jig having a cam instead of a screw.

When making any of these styles of jigs, the holes to contain the bushing may be located by several methods. If extremely accurate work is not necessary, a templet may be made, or a model piece used having the holes properly located; this piece may be placed in the jig and by means of drills, the holes are transferred to the jig. If the bushings are to be used, the holes may be enlarged by a counterbore having a pilot which fits the drilled hole, and a body of the desired size of the bushing. While

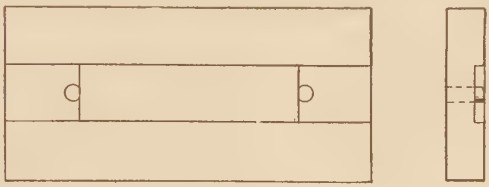

Fig. 236. Locating Ribs on Jig.

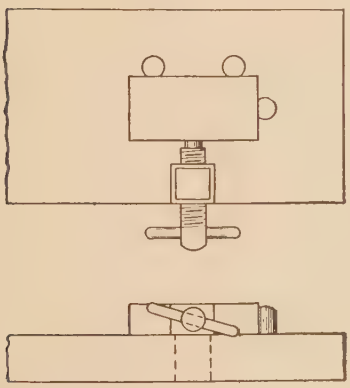

Fig. 237. Jig with Pins and Screw.

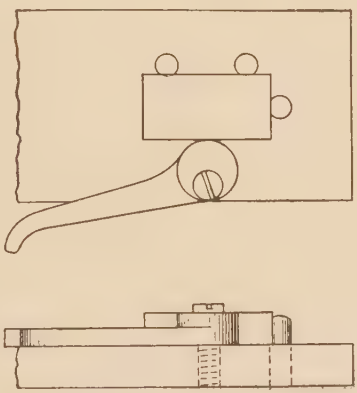

Fig. 238. Jig with Cam and Pins.

this method is cheap, and good enough for certain classes of work, it is not advisable to use it for a very accurate job.

Another inexpensive method which insures *fair* results is to drill the holes as described above, and then run a drill or reamer a trifle larger than the holes in the templet through the holes in the jig. Now place the templet in position; and by means of a counterbore having a pilot which fits the hole in the templet, counterbore the jig

to the templet, as shown in Fig. 239. Better results will be obtained if the ends of the teeth of the counterbore are made of the shape shown in Fig. 240, especially if the drilled hole has run from its proper location.

At times it is advisable to use a hollow counterbore of the

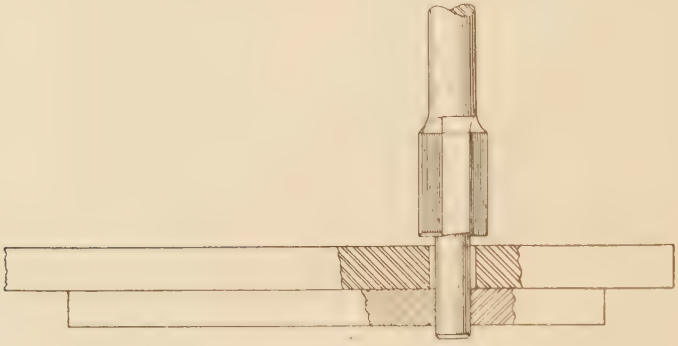

Fig. 239. Counterboring the Jig.

description shown in Fig. 241. A pin having one end a pressing fit in the hole in the model, and the opposite end a nice running fit in the hole in the counterbore, is pressed into the model. The hollow counterbore, being guided by this pin, cuts the bushing hole to size. The results obtained by this method are about equal to those obtained when the previous method is employed

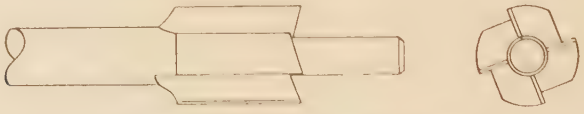

Fig. 240. Special Counterbore for Jig.

A third method is used when the bushing holes must be located by measurement, or when there is no templet or model piece. By means of a surface gauge having the point of the needle set at the proper height from a scale attached to an angle iron, as shown in Fig. 242, scratch a dimension line on the surface which has been colored with blue vitriol. The needle is first set to the height of the locating rib. The scale attached to the angle iron is adjusted so that the needle is at the exact height of one of the inch lines if possible; if not, at one of the half- or quarter-inch lines. The needle may then

be raised to locate the center of the first hole, and a line scratched while the jig is on edge. The centers of the other holes may now be laid off on this plane, after which the jig may be turned one-quarter

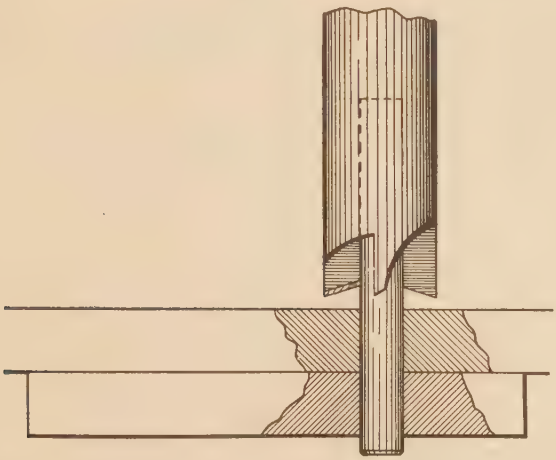

Fig. 241. Counterboring Jig with Hollow Counterbore. Pin is Pressed Solid into Model.

way around to locate the hole from the other measurements. Where the lines intersect, prick-punch the surface of the jig. For this work, *do not* use the center punch made for centering work to be turned in

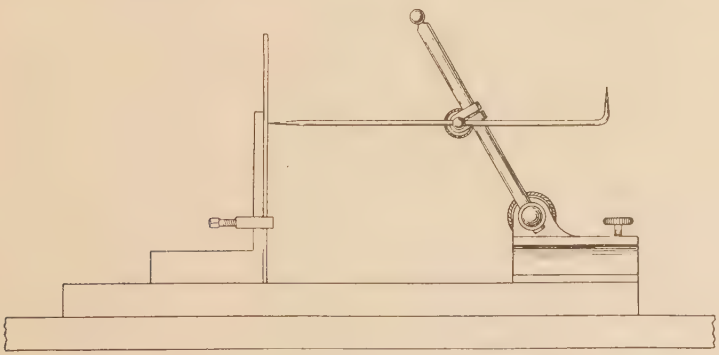

Fig. 242. Locating Holes without Templet.

the lathe. Use the prick punch, which should be much lighter than the ordinary center punch; Fig. 243 shows the two punches. The point of the prick punch should be ground in some form of grinder, in which it may be held and revolved in order that the point may be

perfectly round. If this is not done, it will be impossible to get the point of the center indicator to run true when attempting to true the jig on the face-plate of the lathe.

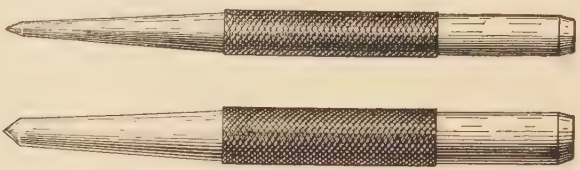

Fig 243. Prick Punch and Center Punch.

While the above method might be properly classed as an approximate measurement, an experienced workman can locate the bushings within a small limit of variation. More accurate work will result if the

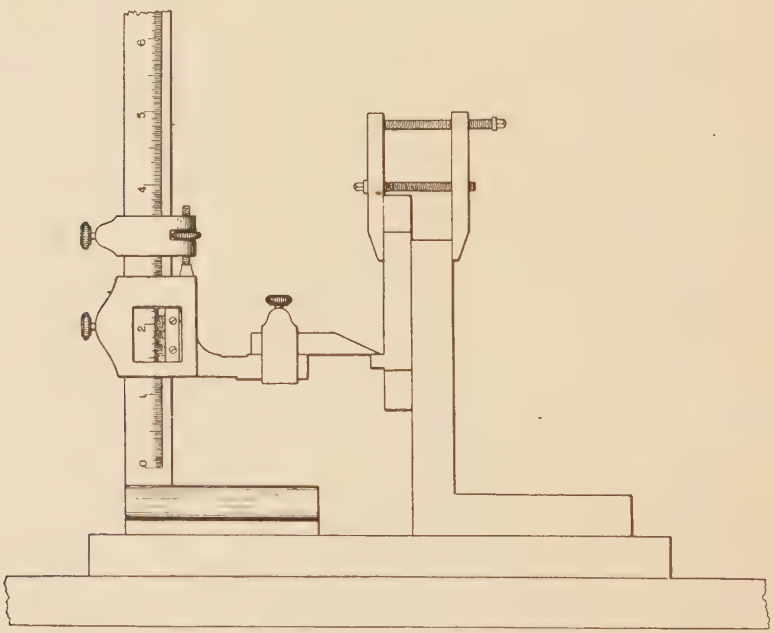

Fig. 244. Accurate Location of Jig with Height Gauge.

height gauge is used in laying off the dimension lines. The bottom surface of the extension is set to the height of the locating rib, as shown in Fig. 244; then, by means of the vernier, it may be raised to the ex-

act height of the dimension desired, and the line scribed by means of the point of the extension.

While this method insures greater accuracy in laying off dimension lines, and is sufficiently accurate for most work, it is open to the objection that the tool-maker may change the location of centers somewhat when prick-punching.

When *precise* measurements are desired, many tool-makers determine the location of bushing holes by means of hardened discs or buttons. A very common size, Fig. 245, is $\frac{1}{2}$ inch diameter, $\frac{3}{16}$ inch thick, and has a $\frac{1}{4}$-inch hole. While it is not essential that the diameter be any particular size, it must be some fraction divisible by two without a remainder, as one-half the size of the disc is considered in all computations. If the disc is .500 inch diameter, .250 inch is the decimal to be considered; but if the disc were $\frac{9}{16}$ (.5625) inch diameter, it would be necessary to consider the decimal .28125 in all computations. In locating the disc, most of the measurements are

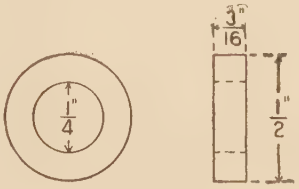

Fig. 245. Hardened Discs for Bushing.

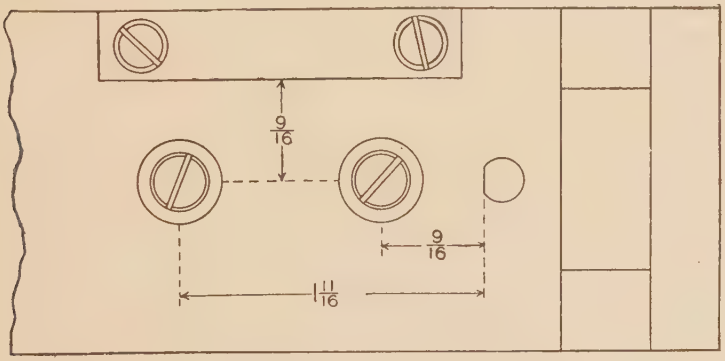

Fig. 246. Jig with Discs Located from Stops.

made with the vernier caliper, and as the tool is not graduated to read closer than .001 inch, it would be impossible to consider the fractions of a thousandth of an inch; consequently discs .500 inch diameter are generally used. The locations of the different holes are laid off by means of the surface gauge, setting the needle to the scale fastened to

an angle iron, as already described. The holes are drilled and tapped for a screw somewhat smaller than the hole in the disc. The discs are now attached to the jig by means of screws. As the screws do not fill the holes in the discs, they may be moved until properly located. Fig. 246 shows a jig having the disc located in relation to the stops.

After properly locating a disc at each point where a bushing is desired, the jig may be fastened to the face-plate of the lathe. The jig must be so located on the face-plate that one of the discs will run

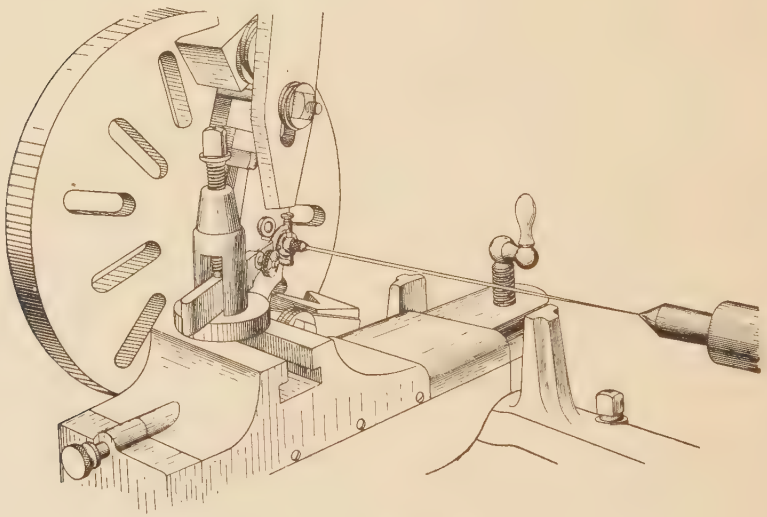

Fig. 247. Test Indicator Truing Discs.

perfectly true. This may be determined by a test indicator operating on the outside of a button, as shown in Fig. 247. After locating so that the disc runs exactly true, the disc may be removed and the hole bored to the required size. The jig may now be moved to bring another disc to the proper location, after which it may be removed and the hole bored; this operation may be repeated until all the bushing holes are bored.

Boring Bushing Holes on Milling Machine. In order accurately to locate and machine drill-jig bushing holes on a universal milling machine, it is necessary to use a machine provided with a corrected screw and index dial for each of its graduated movements.

With such a machine and proper tools, it is possible for the skilful workman to produce a drill jig that is correct within reasonably narrow limits. If many jigs are made and corrected screws are furnished, it is not advisable to use the machine for heavy milling. Many shops providing themselves with such a machine do not use it for anything but jig work, and laying out models and similar pieces.

The skilful workman always looks the drawing of the jig over carefully, and selects a suitable working point to start from. This working point should be one where it will be possible to move in directions necessary in locating the other working points, so that no backlash will occur in the adjusting screws. In other words we must commence at one end and move ahead all the time. It may be necessary to raise and lower the knee of the machine to get vertical adjustments; but we should, when lowering, rather run the knee below the desired point than raise it up to it; in this way we avoid error.

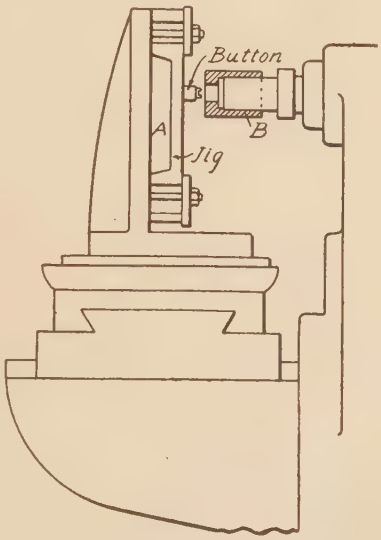

Fig. 248. Drill Jig Fastened to Angle Iron for Drilling.

If the jig can be fastened to an angle iron as shown in Fig. 248, the face of the angle iron against which the work is clamped should be set exactly parallel to the travel of the table of the machine. A *bath indicator*, or an indicator of the design shown in Fig. 249, may be clamped to an arbor in the spindle of the machine; or one may be held in a chuck screwed on the nose of the spindle or in one with a shank, fitting the hole in the spindle, as shown in Fig. 250. By running the table of the machine back and forth with the contact-point of the indicator against the face of the angle iron, and moving the iron until there is no change in position of the indicator needle, it may be correctly located.

A button is attached to the jig at exactly the location of the first bushing hole. The jig is fastened to the angle iron, and the proper

adjustments made so that the sleeve *B*, Fig. 248, will slide over the button, making sure that the table of the machine is moving in the direction necessary to get the other adjustments. In order to insure accuracy, it is necessary to use a sleeve *B* having a hole which is a

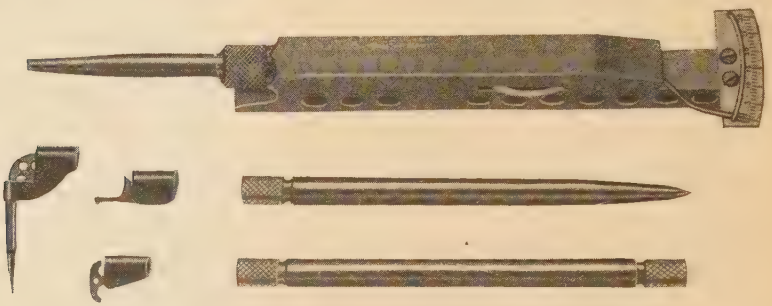

Fig. 249. Indicator for Locating Bushing Holes.

nice sliding fit over the button. In order that the sleeve may be exactly true, it is necessary to make the outer end of the stud somewhat large, then turn it after it is placed in the collet, the cutting tool being held in the milling-machine vise. The stud revolving with the spindle may be turned by bringing it in contact with the cutting tool; the tool feed may be obtained by moving the saddle. As the modern milling machine is provided with automatic saddle feed, a very smooth cut may be obtained. Excellent results follow if an electrically driven grinder, shown in Fig. 251, is fastened to the table of the machine, and the stud ground to size. It is obvious that the sleeve must be a nice fit on the stud.

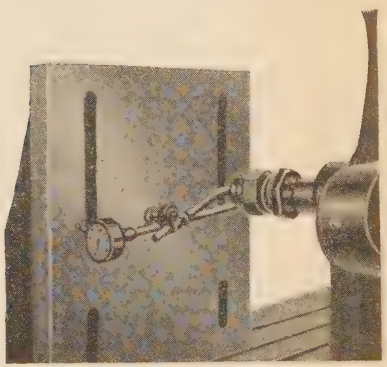

Fig. 250. Indicator with Sharp Fitting Nose on Spindle for Locating Bushing Holes.

When the jig has been properly located, the stud may be removed from the collet, the button taken from the jig, a drill placed in the collet, and a hole drilled through the jig. A boring tool may now be placed in the collet, and the bushing hole bored to size. Various forms of boring tools are used for work of this kind. A very satis-

factory form is shown in Fig. 252, the cutter being securely held by the set screw shown. When using this form of boring tool, the cutter may be moved out any desired amount, the amount being measured by the micrometer.

After boring the first hole, the table may be moved the desired amount to bring the next location into position for drilling and boring. If it is necessary to drill and bore bushing holes in the piece shown in Fig. 253, a button being fastened to the surface at *A*, after locating as previously described, the button is removed, and the hole drilled and bored to desired size; the carriage is then moved 1.1875 inches, and the hole is drilled and bored. The knee is then raised 1.0625 inches; the hole *B* is drilled and bored; the carriage is again moved 1.250 inches, and the hole *C* drilled and bored. The jig is then removed from the angle iron, the bushings made, hardened, ground, and forced to place.

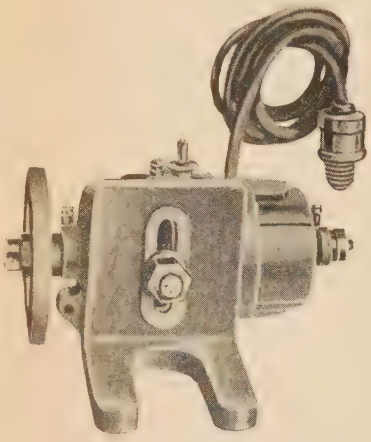

Fig. 251. Electric Grinder for Grinding Stud to Size.

In the case of a jig that is to be made to a model, the model is exposed if the jig is provided with a leaf, which may be thrown back. Now, by means of a plug inserted in one of the holes, the jig may be

Fig. 252. Boring Tool for Drill Jig.

accurately located until the sleeve on the stud rings over the plug. The plug may be made with one end a nice fit in the hole in the model, and the other end a nice fit in the sleeve. When the jig is accurately located, the leaf may be closed, and the hole drilled and bored as in the previous example.

When jigs are made for permanent equipment, or if they are to

be used constantly, it is well to provide some means of elevating them from the drill-press table to avoid inaccurate work occasioned by chips. When the jig is made of cast iron, the legs are sometimes cast solid with the jig as shown in Fig. 254. In order to grasp a jig handle in a manner that will not be tiresome to the wrist or hand, and allow sufficient room between the handle and the table of the drill press so that

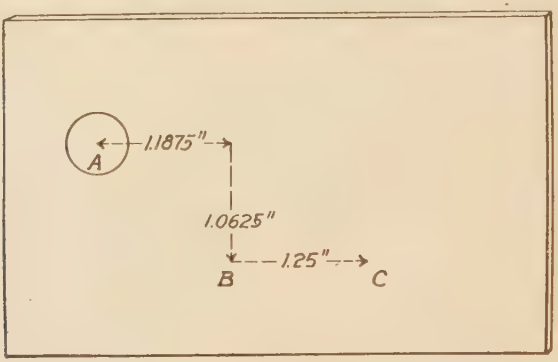

Fig. 253. Location of Bushing Holes in Drill Jig.

the fingers may not be cut by chips, the legs are made of a length that will raise the handle about $1\frac{1}{8}$ inches above the table. As cast-iron legs of this length would be too weak, it is customary to make the legs of tool steel, hardening the ends that come in contact with the drill-press table.

While the form of jig shown in Fig. 233 would give satisfaction

Fig. 254. Cast Iron Jig with Solid Cast Legs.

on certain classes of work, the process of putting the work in and taking it out of the jig would be very slow, as it would be necessary to clamp the work securely to resist the pressure of the cutting tools.

In order that work may be handled rapidly during these operations, jigs are designed so that the work will rest on the base of the jig as shown in Fig. 255. A leaf or cover containing the bushings can be raised when putting the work in place and taking it out.

When the pieces to be drilled are of a uniform thickness, the leaf may be made to rest on the piece; but should the pieces vary in thickness, the leaf would not be parallel to the base; consequently the hole in the bushing would not be at right angles to the piece to be drilled. For this reason a little space is left between the top of the piece to be drilled and the bottom of the leaf as shown in Fig. 256; a steady pin

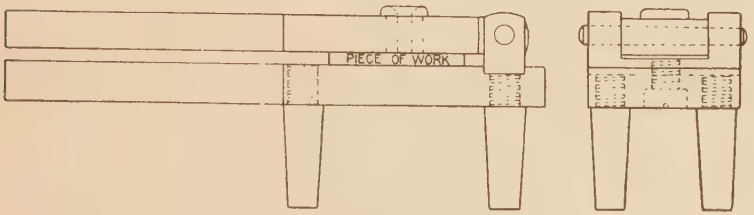

Fig. 255. Jig with Cover.

having a shoulder is located at the handle end of the jig. The upper end of the pin may project into a hole in the leaf, as shown, thus relieving any strain on the joint of the jig occasioned by the action of the cutting tools.

When holes are to be drilled from opposite sides of a piece of work, as shown in Fig. 257, a jig may be constructed having legs on

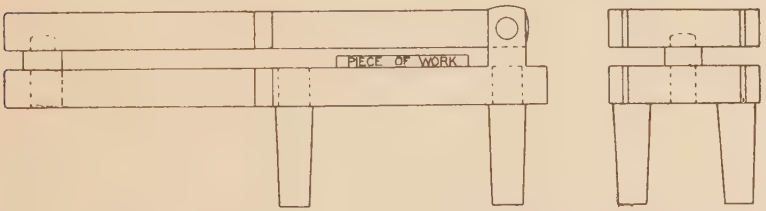

Fig. 256. Covered Jig Showing Space between Work and Leaf.

both upper and lower sides, but both sets of legs should be solid with the base, as shown in Fig. 258.

If the two end holes in Fig. 257 are of the same size, and it is necessary to use a drill press having but two spindles, the legs on each side should be of a length that would make it possible to set the stops so that the drill would cut the required depth on each side. If a drill press having three or more spindles is to be used, the jig legs may be of a convenient length, as two drills of the same diameter can be used

in two different spindles, each one to drill the required depth when the stop is set.

Drill jig legs are generally made of tool steel and are screwed into the base of the jig; the thread on the legs should be a good fit in the base. After screwing in place, the ends of the legs should be machined to length by milling or planing; the legs may then be removed, and the ends that come in contact with the drill-press table hardened. The legs may now be polished (if that is allowable), and then screwed in place. The ends should now be ground to such a length that the surface where the work is seated will be of the correct height above the drill-press table.

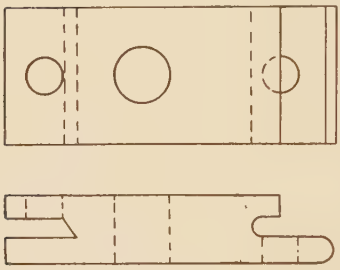

Fig. 257. Holes Drilled from Both Sides.

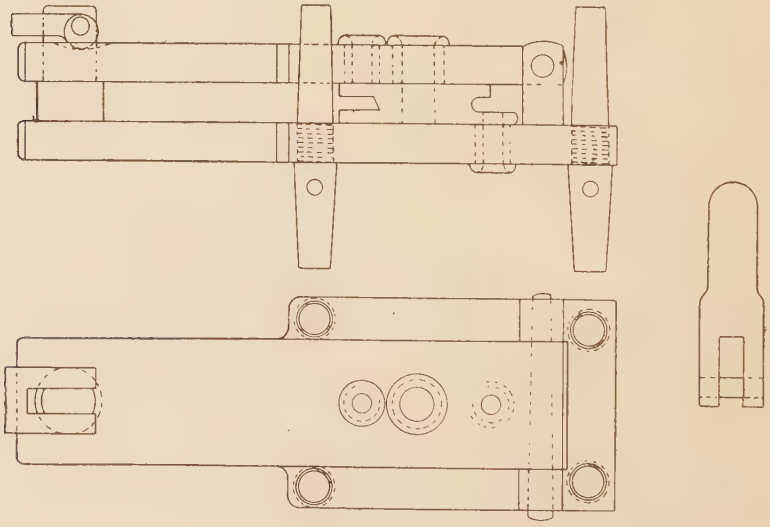

Fig. 258. Jig with Legs on Both Sides.

Grinding the ends of the legs can best be done in a surface grinder, or some form of universal grinder designed for surface grinding. After grinding, the ends of the legs may be lapped to remove any irregularity that may result from grinding. A very good lap may

be made from a flat plate or block of cast iron. The surface to be used may be planed flat and smooth, then a series of grooves cut to form squares, as shown in Fig. 259. These grooves may be cut with a V-shaped tool and should be $\frac{1}{4}$ inch apart, and $\frac{1}{64}$ inch to $\frac{1}{32}$ inch deep. The grooves catch the emery and feed it to the work being lapped. If the pressure is not equal, one leg may be cut shorter than the other, or may be lapped out of true, causing the jig to rock.

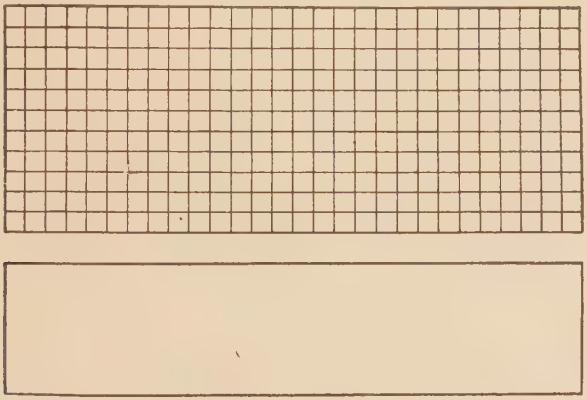

Fig. 259. Jig Blank Grooved and Ready for Lapping.

Jigs with Cored Holes. As large jigs are usually made from cast iron, and as it is advisable, when the holes are large, to core them, it is necessary, in order to lay off the location of the center of the desired hole, to insert a piece of steel or brass in the hole and then lay off the desired point on the inserted metal as shown at *a*, Fig. 260.

Where the *button* method is to be used, a button of a size somewhat larger than the cored hole must be used; and this, bolted against the face of the boss in the proper location, enables the workman properly to locate the jig on the face-plate of the lathe, or, if too large to swing in the lathe, it may be fastened to the table of the boring mill, and trued by means of an indicator held in the cutter head of the machine; or the jig may be attached to the milling-machine table, and the bushing hole bored as described under the head of "Boring Bushing Holes on the Milling Machine."

When properly located, the piece of brass and steel may be knocked out of the hole, or the button may be removed and the hole bored to desired size. Many tool-makers always drill or file the walls of a cored hole to remove all hard scale, as there is always more or less liability of knocking a piece of work out of true when cutting through cast-iron scale. When the scale is removed before machining, there is little liability of moving the work if it is securely clamped to the machine, and the workman is reasonably careful when machining.

When doing work of this character, the workman is not expected to take such heavy cuts as would be taken on manufactured articles where they are securely held in specially designed holdfasts; and he

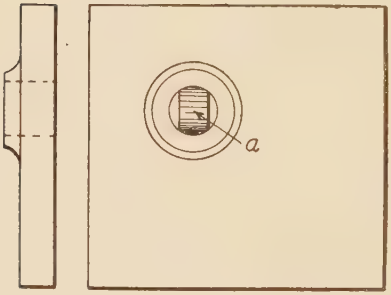

Fig. 260. Locating Center of Cored Hole in Jig.

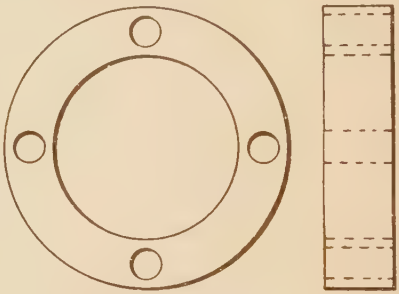

Fig. 261. Use of Buttons in Using Boring Bar for Bushing Holes in Jig.

should be particularly careful when taking cuts where there is more stock to remove on one side than on the other, as the unequal strain is especially liable to throw work out of true.

As indicated in another place, *never* ream a bushing hole, always machine to size with an inside turning tool, or with a boring bar, where such a tool can be used.

Under certain conditions, especially where a boring bar is to be used, either in the boring machine or in the lathe where the work is to be fastened to the carriage and the boring bar supported on the centers of the lathe, buttons are used which have several holes passing through them, as shown in Fig. 261. These holes are somewhat larger than the cap screws to be used in attaching the button to the face of the jig. The button has a hole through the center $\frac{1}{16}$ or $\frac{1}{8}$ inch larger than the desired hole in the jig. It is accurately located on the face of the jig, which is then placed on the machine and fastened in position. To

locate the jig properly, the boring bar is passed through the cored hole and placed in position; then by measuring from bar either to outside of button, or to the wall of hole, the jig may be located so that the button is equidistant at all points from the bar.

The advantage of this form of button is that it can be left in position on the jig while the hole is being bored; and when the hole is finished, a plug may be inserted, and the hole tested for accuracy of location.

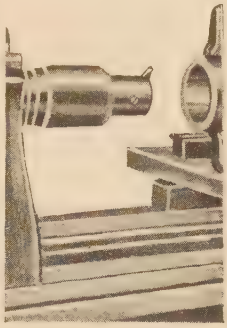

Fig. 262. Boring Cutter for Holes Which Pass Partly Through Jig.

At times it is desirable to use the above described method, when the hole passes through but one side of the jig, and it would not be possible to carry it through the other side. In such a case a boring tool which screws on the nose of the spindle or fits into the spindle hole may be used. Such a cutter is shown in Fig. 262.

EXAMINATION PAPER

TOOL-MAKING

PART II

Read carefully: Place your name and full address at the head of the paper. Any cheap, light paper like the sample previously sent you may be used. Do not crowd your work, but arrange it neatly and legibly. *Do not copy the answers from the Instruction Paper; use your own words, so that we may be sure that you understand the subject.*

1. Why is it not advisable to make the lands of screw threading dies wider than described? What is the result if they are made narrower?

2. Under what circumstances would you consider it advisable to use a counterbore, rather than a drill, when enlarging a hole. Why?

3. Why would it not be considered good practice to turn the piece of stock represented in Fig. 136 to size before drilling the holes and working the slots to size?

4. Why is it not advisable to make a hollow mill to be used in roughing out work, having more than 4 teeth?

5. Why is it advisable to give a finish hollow mill more than 4 teeth?

6. When hardening a hollow mill of the form shown in Fig. 152, why is it advisable to dip it in the bath with the cutting edges uppermost?

7. In using a forming tool why is it necessary to have the face of the tool at the height of the center?

8. Give the advantages derived from using a forming tool and holder of the design shown in Fig. 168.

9. Why is a milling-machine cutter more likely to crack when hardening than other forms of tools?

10. Why is it not good practice to ream holes in milling-machine cutters to finish size?

11. What is the result if the hole in a milling-machine cutter does not fit the arbor?

12. When is it advisable to use milling-machine cutters having interlocking teeth?

13. When is it advisable to use milling-machine cutters having their teeth cut spirally? Why?

14. When is it advisable to cut the teeth of milling-machine cutters with a right-hand spiral? When, a left-hand spiral? Why?

15. State advantage gained in making milling-machine cutters with nicked teeth.

16. Why is it generally considered advisable to make milling-machine cutters that are larger than 6 or 8 inches diameter with inserted teeth.

17. When a blank for a milling-machine cutter that is to have inserted teeth is milled with slots that are at angle to the cutter axis, why is it not advisable to leave the faces of the teeth at that angle?

18. If an emery wheel, 3 inches in diameter, is used in grinding the teeth of a milling-machine cutter, how many revolutions must it make in a minute in order to run at a peripheral speed of 5,000 feet per minute?

19. Why is it not generally considered good practice to make key ways in milling-machine cutters with sharp corners?

20. State in your own language the generally accepted meaning of the term "formed cutter" or form cutter.

21. Name some of the advantages derived from the use of formed cutters.

22. What would be the result if the faces of the teeth of a formed mill were not recut after they were backed off?

23. When backing off the teeth of a formed mill, what would be the result of setting the forming tool above or below the center of the work?

24. When making milling-machine cutters with threaded holes, why is it necessary to first thread the blank, then machine it on a threaded mandrel?

What would be the result were the cutter machined to shape before threading the hole?

25. When machining a piece of work having a threaded hole, why is it not advisable to screw the piece onto a threaded mandrel in such a manner that the shoulder of work is against the shoulder of mandrel when squaring the first end?

26. When are fly cutters used? Name some of the advantages of using them where they will answer the purpose.

27. When are end mills used?

28. Why are collets used in holding end mills?

29. Why is it advisable to turn, or grind the shanks of end mills after the mills are hardened?

30. When grinding the teeth of milling-machine cutters for clearance, what is the result if the angle of clearance is too great? What, if it is not sufficient?

After completing the work, add and sign the following statement:

I hereby certify that the above work is entirely my own.

(Signed)

Completed
May 5 - 1916.

Roy Benjamin

Y0-BUT-517